AFAL-TR-78-45



# SATCOM TERMINAL EHF/UHF TEST PROGRAM SYSTEM RELIABILITY ANALYSIS

*SYSTEM DEVELOPMENT BRANCH*
*SYSTEMS AVIONICS DIVISION*



APRIL 1978

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Final Report for Period January 1976 to November 1977

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This technical report presents the results of an analysis of the operational reliability for the EHF/UHF SATCOM System flight test program conducted by the Air Force Avionics Laboratory during the period of January 1976 to November 1977. The report was prepared as a case study covering a relevant literature review in such areas as reliability analysis models, methods to increase reliability, and SATCOM system reliability estimates. (continued)

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In addition, the study covered the data acquisition approach and data analysis results based on the reliability data obtained from the test program. Supporting appendixes covered such areas as the approach to estimating MTBF and the procedure for the calculation of the Confidence Interval as related to the MTBF.

## FOREWARD

This technical report, AFAL-TR-78-45, describes the assessment of the operational reliability for the EHF/UHF SATCOM System Test Program conducted by AFAL during the period of January, 1976 to November, 1977. The work reported was accomplished under work unit No. 1227-0124 "Ka-Band System Reliability Improvement". The Test Program Manager was Mr. Allen Johnson, and Mr. Herbert M. Bartman was the Project Engineer for Reliability. The report was also presented by the author, Mr. Herbert M. Bartman, as a case study to the faculty of the Graduate School of Engineering, University of Dayton, in partial fulfillment of the requirements of ENM 590, Case Studies in Engineering Management.

## ACKNOWLEDGEMENTS

In the conduct of this study, a large number of individuals were called upon to assist in the data acquisition during the test program. Thanks are extended to each of the assigned engineers and technicians from the Raytheon Company, TRW Incorporated, RCA Corporation, and Rockwell International, Collins Telecommunications Division, for maintenance and repair support during the test program. The listed companies were under contract to the Air Force to provide engineering services as part of work unit 1227-2205 titled "SATCOM Testing". In addition, thanks to Messrs. Easterday and Drennan at Battelle Columbus Laboratories under Contract F33615-77-C-1208 for preparing the malfunction report/data

acquisition forms and for providing a computer routine used to tabulate and plot the data collected during the test program. Thanks are also extended to Mr. Ken Cunningham of The Air Force Avionics Laboratory (DOM) for his support in tabulating and plotting the data collected during the test program and presented in Appendix A.

Appreciation is expressed to Dr. John Fraker, Director of the Engineering Management Program of the University of Dayton, for his guidance in the preparation of this report.

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## GLOSSARY OF ABBREVIATIONS

| | |
|---|---|
| AFAL | Air Force Avionics Laboratory |
| AFSATCOM | Air Force Satellite Communications |
| BCL | Battelle Columbus Laboratories |
| CSEL | Communications System Evaluation Laboratory |
| DSCS | Defense Satellite Communication System |
| E-4 | Airborne Command Post Aircraft |
| EHF | Extreme High Frequency - 30-300 GHz |
| EXP | Exponential Function |
| FREQ SYNTH | Frequency Synthesizer |
| HF | High Frequency |
| HPA | High Power Amplifier |
| IBM | International Business Machines |
| INS | Inertial Navigation Systems |
| KaBand | 30 to 40 GHz |
| K-S | Kolmogorov - Smirnov |
| LES | Lincoln Experimental Satellite |
| LNA | Low Noise Amplifier |
| MIL-HDBK | Military Handbook |
| MIT | Massachusetts Institute of Technology |
| MODEM | Modulator and Demodulator |
| MTBF | Mean Time Between Failure |
| MTBO | Mean Time Between Occurrences |
| R/M | Reliability and Maintainability |
| SATCOM | Satellite Communications |

| | |
|---|---|
| SHF | Super High Frequency |
| SYNCH/DEMUX | Synchronization and Demultiplexer |
| TASRA | TAbular System Reliability Analysis |
| TWT | Traveling Wave Tube |
| UHF | Ultra High Frequency |
| U-I/O | Input and Output Devices for UHF System |
| VLF | Very Low Frequency |

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CHAPTER 1

GENERAL

INTRODUCTION

Satellite Communication (SATCOM) systems currently being developed for military airborne command post application will be required to provide reliable command and control communications. The Air Force Avionics Laboratory (AFAL) has been involved in the Satellite Communication (SATCOM) Airborne Terminal development program since 1972. The SATCOM Terminal addressed in this investigation was developed to work with the Lincoln Experimental Satellites (LES) Numbers 8 and 9 in the 36 to 38 GHz extra high frequency (EHF) band and the 225 to 400 MHz ultra high frequency (UHF) band. These test satellites, Figure 1, are representative of the type that will be part of the world-wide jam resistant communications link between the Airborne Command Post aircraft (E-4) and the force elements (bombers and missiles) as discussed in the AFSC News Review (12), the Aviation Week and Space Technology (11) and the flight test report by James Miller entitled "SURVSATCOM (Ka-Band) Flight Test" (17).

The recently completed EHF and UHF SATCOM Flight Test Program provided three outputs in terms of system performance analysis, next generation design update and reliability and maintainability (R/M) model update. These outputs included:

1. data for a meaningful evaluation of the system

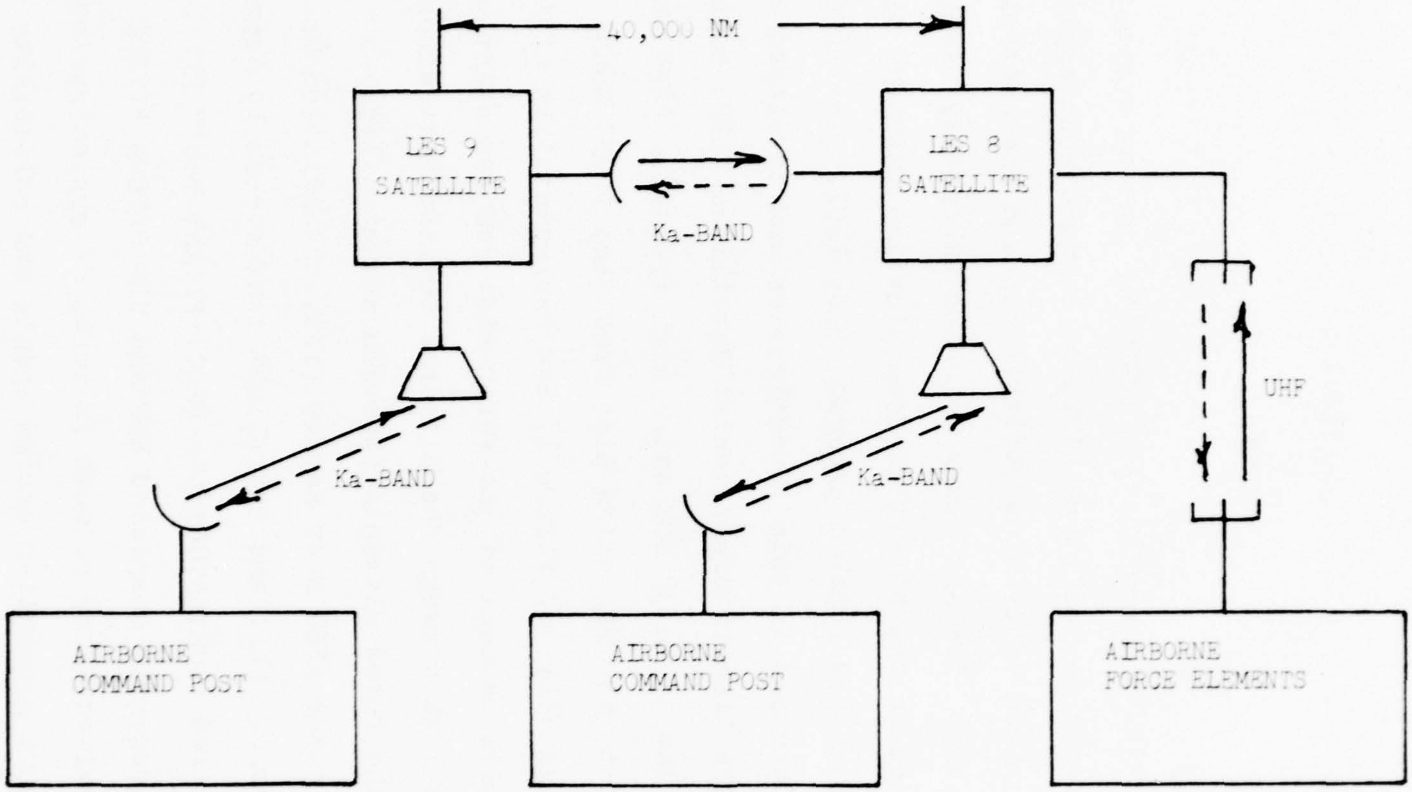



Figure 1

Simplified Block Diagram
SATCOM SYSTEM (1)

reliability

2. reliability data for the preparation of quantifiable aspects for the next generation dual frequency SATCOM Set development

3. the update of R/M models currently under development at Battelle Columbus Laboratories (BCL) as discussed by J.F. Drennan and J.L. Easterday in a technical memorandum entitled:"Reliability Analysis of the SATCOM Terminal" (4).

At the outset of the test program, a requirement was established to assess the ongoing system reliability prior to proceeding with the planned follow-on development program for advanced SATCOM systems.

PROBLEM STATEMENT

The ultimate output of a system is the performance of some intended function. For the Military Airborne Command Post, this can be described as a reliable command and control communication function. Some of the major attributes that influence system performance greatly are those of reliability, maintainability and availability.

In this study, the reliability of the Ka-Band and UHF SATCOM Sets are addressed in order to assess, in some detail, their reliability characteristics. In addition consideration is given to such questions as: (1) How realistic is the observed Mean Time Between Failures (MTBF) value for the groups under study when compared to an exponential

distribution? (2) How well does the observed MTBF compare to the predicted?

ANALYSIS LIMITATIONS

The analysis is limited to the Airborne Command Post EHF and UHF equipment reliability and not to the likelihood that other elements of the SATCOM system are operational. Also the analysis is not concerned with quality of the operational performance of the various links, but only with the reliability of these links.

METHOD OF ATTACK

The plan of attack in this study includes, as described in subsequent chapters and appendixes, a coverage of research methods and techniques used, a test plan describing data needed to test the question of the problem under analysis, the source of such data, the techniques for gathering and reducing the data, and a description of the tools and techniques for analyzing the data.

Data were gathered from the libraries at the University of Dayton, Air Force Institute of Technology, the Air Force Avionics Laboratory (AFAL), the U.S. Army Materiel Command Pamphlets pertaining to reliability requirements, personal libraries of personnel at AFAL, and the Department of Defense Military Standards and design handbooks. Personal interviews were conducted with maintenance personnel concerned with the EHF and UHF test programs. SATCOM program malfunction reports and event logs were used to obtain failure data and

time of failures. A description of tools and techniques for collecting data is covered in subsequent chapters. This report addresses a description of an airborne satellite communication (SATCOM) set and includes a section that describes techniques for analyzing the data collected and the identification of statistical techniques and sources.

PREVIEW OF REPORT CONTENT

Chapter 2: a review of the relevant literature concerning Satellite Communication Systems and reliability briefly addresses the need for reliable communication systems in the near term. In the remainder of the chapter, the importance of system reliability is discussed. In addition, the latest system reliability analysis approach is discussed. Also, basic reliability measurement and test concepts are reviewed and applied.

Chapter 3: in this chapter, the Satellite Communication System (SATCOM) addressed in this study is described. In addition, the SATCOM system reliability aspects are discussed and SATCOM system reliability models described.

Chapter 4: in the data acquisition chapter, a data acquisition approach is given as part of a test plan. This plan was accomplished with a minimum interference to the ongoing Flight Test Programs. The remainder of this chapter covers the approach taken for data collection and reduction.

Chapter 5: the data analysis chapter presents the reliability data in both tabular and bar graph format to

enable the reader to determine his own findings. In addition, an analysis is conducted with data obtained from the Flight Test Program and with system reliability estimates provided by the contractor, Battelle Columbus Laboratories (BCL). This results in the finding that certain groups of equipment within the system under analysis experienced the most failures. The reliability model, as given in chapter 3, is instrumental in determining which equipment would need reliability improvement.

Chapter 6: in this chapter the conclusions and recommendations for further study are presented. These are based on analysis of the data presented in previous chapters. In this study, the Communication Terminal Group-30 would appear to require the most attention.

## CHAPTER 2

## REVIEW OF RELEVANT LITERATURE

### SATELLITE COMMUNICATION SYSTEMS

Satellite communications (SATCOM) systems are presently being developed for military airborne command post applications for the direction of U. S. Forces located world-wide. Satellite systems operating at various frequencies are being implemented. The requirement for a reliable and secure world-wide communication system exists using the Command Post aircraft. Because of the importance of communications for command and control, no single communication mode can be depended upon to satisfy the total communication requirement. The existing communication systems which fulfill these requirements include high frequency (HF), very low frequency (VLF), and line of sight relay of ultra high frequency (UHF) and above. A new class of communication systems is now being developed in order to improve the communication reliability and to increase coverage. This new class of communication systems involves a system which uses a line of sight relay through a satellite to increase coverage. An informative discussion of satellite communications is found in a brochure prepared by AFAL, entitled Air Force Avionic Laboratory SATELLITE COMMUNICATION PROJECT (1).

The Command Post aircraft (E-4) is being equipped with a super high frequency (SHF) satellite communication system which will operate over the Defense Satellite Communication

System (DSCS). Also contact between the command post and the aircraft's defense forces will be provided by the Air Force Satellite Communication System (AFSATCOM), which uses ultra high frequency (UHF) band to provide teletype communication between the command and the force elements. To increase communication survivability and reliability, a new SATCOM system was developed using the extra high frequency (EHF) band. This new system will be based on the concepts provided by the Lincoln Laboratory, which is part of the Massachusetts Institute of Technology.

The Air Force Avionics Laboratory (AFAL) recently completed a flight test program to prove technology and demonstrate system feasibility using the Lincoln Experimental Satellite (LES) Numbers 8 and 9 operating in the EHF band. In order to use both the EHF and SHF SATCOM systems on the E-4, the Air Force Avionics Laboratory, according to Allen Johnson in his paper entitled "Dual Frequency Satellite Communication System", is developing a dual frequency SATCOM system which will allow operation in either the SHF or EHF band.

SYSTEM RELIABILITY

Importance of Reliability Electronic systems are the heart of the satellite communication airborne command post. It is not enough for these systems to work most of the time, because national defense is too critical. However, as stated by Lt. Gen. Bryce Poe, II in his paper entitled "AFALD: Making

Better Electronics Affordable"(19): "In this day of diminishing resources, we must also add the word 'affordable', since increased performance is required to match the increasing threat,balancing complexity, capability, and maintainability with reliability and cost is a great challenge for both the Air Force and the Electronic Industry". Therefore, in the final analysis, cost of an electronic system is tied directly to reliability and maintainability. Lack of either greatly increases costs. This is what life cycle cost is about -- the trade-off between the cost of designing reliability in an affordable system now and the increased cost of making it work later, as discussed by Dummer and Winton in their text entitled "An Elementary Guide to Reliability"(5).

Complexity and Capability versus Reliability The ever-growing needs of Mission Critical Avionic Systems results in equipment of ever increasing complexity. As the number of components in a piece of equipment is increased, the probability of failure of that equipment is increased. The technology necessary to advance capability does tend to increase complexity, but it could also increase reliability. However, improved capability does not automatically improve reliability. There are trade-offs which may have to be made because resources are limited. A level of reliability less than that desired may have to be accepted in order to stay within the state-of-the-art and, just as restrictive, budget limitations. Space and weight are competitive factors.

Reliability may have to be sacrificed to fit the equipment into the advance communication system at the cost of increased maintainability. Therefore, maintainability of the equipment must be given continuing consideration. Lloyd and Lipow addressed the above in some detail as part of the introduction to their text entitled "Reliability: Management, Methods, and Mathematics" (13).

## Methods of Achieving Reliability Improvement

1. Design. The reliability of any piece of equipment is molded by its design and manufacture. The result of design on reliability is to establish the inherent reliability of the equipment. This level of inherent reliability cannot be surpassed without design changes. Reliability must be considered when a demand exists for a new piece of equipment. The best method to achieve reliability is to buy the design in the initial procurement contract. Shooman, in Chapter 6 of his text entitled "Probabilistic Reliability: An Engineering Approach" (23) discusses the need for a design to assure reliability improvement.

2. Testing. The Department of Defense requires reliability to be stated in quantitative mission-responsive terms for all development programs. The reliability goal must be based upon technically realistic requirements that can be contractually specified and demonstrated. The concept of reliability revolves around the ability of a system to perform its intended function. The function or mission of the system must be defined, together with the expected operational environment

of the equipment. The reliability requirement must be expressed in the contract in terms that are attainable and measurable to enable the requirement to be enforced. The MTBF (Mean Time Between Failures) is the measurement used here for reliability. Reliability, as a function of time and conditions, is measured in terms of mean time between failure under specified conditions. Testing provides information that can aid in the evaluation of the equipment's reliability. The amount of testing performed is limited because testing costs money. A testing program may, however indicate a weakness in the equipment that would not otherwise be discovered until the equipment is in the operational environment. With the information obtained from testing, the engineer can evaluate possible design changes to meet the required level of reliability. In Chapter 4, of the Army Materiel Command Pamphlet 706-198, the needs for positive test management and planning are discussed (21).

3. Modification. Another method of improving reliability is by means of component improvement as discussed by Shooman in Chapter 6 (23). A piece of equipment can be made more reliable by replacing the high failure rate items with more reliable parts, circuits, or assemblies. To use a modification program to its best advantage, there must be an information system that will indicate the part that is failing, how it failed, when it failed, and why it failed. Modification is limited to correcting the shortcomings of design and

and manufacturing and the effects of unforeseen conditions in the actual environment in which the equipment is called upon to operate. However, modification, at best, is a patch on the equipment and modification may not be economically justified. Technology advances may point to new equipment as a better cost-effectiveness alternative. Although modification is a method of increasing reliability, it is a "find-it, fix-it" operation. It is used only because the original design and manufacture fell short of the goal.

4. Redundancy. Redundancy is another method whereby reliability of equipment may be increased. Redundancy is the use of two or more components, circuits, or items to perform a function which normally requires only one of these circuits, components, or items. In redundancy, a failure of all duplicate items capable of performing the function must occur before the failure to perform the function exists. An advantage of redundancy is that it may be the quickest solution to a reliability problem when time is of prime importance. It may even be the cheapest solution if the components are economical when compared to the cost of redesign and manufacture of the new equipment. The disadvantages of using redundancy to improve reliability are numerous. For example, the components necessary to duplicate the function may be very costly. Added circuits or components would require added space and weight. In addition, redundant items may attenuate the input signal, causing a need for additional amplifiers, which in turn

increases the complexity of the equipment. From an analysis of the advantages and disadvantages of redundancy, the greatest gain in increased reliability by the use of redundancy will be on items that have a low reliability or critical reliability as discussed by Von Alvern in his text entitled "Reliability Engineering" (28).

5. Derating. Derating is another method used by design engineers to increase reliability in electronic equipment. In derating, equipment designed for operation at a certain level uses parts designed to operate at a higher level. The main advantage of derating, as discussed by Shooman in Chapter 6, is that it will tend to increase the life expectancy of the equipment (23). However, derating tends to increase manufacturing costs because parts used to derate may cost more than the parts actually required to satisfy design specifications.

## The TASRA Model

General The TASRA (Tabular System Reliability Analysis) model was developed by BCL for performing reliability analyses of complex systems. It is well suited for this purpose in that the model can simulate real-world situations in which a malfunction occurs in the system but major portions of the system remain operational, as well as situations involving a complete failure of the system. The TASRA model is computer-based and configured so that the detailed functional interrelationships of the system components are represented in the reliability model. Thus, failure of a subassembly or assembly

in the real system will have the same effect on the system operation as the reliability model depicts. In a TASRA analysis, the term "malfunction" means a sometimes acceptable degradation in functional performance and the term "failure" is used to indicate complete cessation of functional perfomance of the component or assembly. A detailed discussion of the TASRA model is given by Easterday and Drennan in the special interim report entitled "Preliminary Ka-Band Availability, Reliability and Maintainability Estimates"(6).

<u>Overview of Specific Modeling Procedure</u> The TASRA user must generate a functional description of the total system and its subsystems, major assemblies, subassemblies, etc. The most important criterion in this step is to select "building blocks" such that a failure of each is logically independent of the failure of the other "building-blocks" at that system level. A diagram is prepared to document this partitioning at each level. This level-by-level set of partitioned functional diagrams is one of the basic inputs the analyst must prepare when using the TASRA computer model. Another concept essential to an understanding of the TASRA model is that of system states. The state of the system can be:

1. fully operational, as the specifications define it,
2. failed (complete cessation of functional ability) called failure state, or
3. in one of several degraded operating modes--called malfunction states.

The TASRA model can be used to predict the probability of occurrence of each state defined for each level of the system at which an analysis is conducted. This can be expressed as a MTBO or mean time between occurrence. A primary objective of the development of this model has been to orient it toward the user. From the user's viewpoint, the performance of the Ka-Band SATCOM terminal is measured by its availability at the time the user needs to send or receive a message. Thus, the message availability to meet a mission profile defines the numbers of communications that can be completed for each alternative communication mode as functions of mission time. One specific measure employed is the dependability; that is, the probability that a specified number of communications will be initiated and completed without the occurrence of delay resulting from equipment malfunction. A second measure of terminal performance is "expected communication delay", which is defined as the "best estimate" of the delay in completing a communication that results if the equipment malfunctions. The above overview was discussed by Easterday and Drennan in Reference 6.

RELIABILITY MEASUREMENT

One advantage of a probabilistic approach when compared to a deterministic approach is the capability to provide a good measure of the uncertainty involved in a numerical analysis, as discussed in Chapter 2 of the Army Materiel Command Pamphlet Pamphlet 706-198 (21). Another advantage is

that a method is provided for estimating effects that otherwise might be lost in the random variation of the data.

The designer-engineer must solve a real-world problem; therefore, the estimation of uncertainty is important. The basic concept of statistical testing, as related to point estimates and interval estimates during system design and development, are briefly discussed in the appendixes.

The three types of parametric estimates most frequently used are point estimates, interval estimates, and distribution estimates. They can be defined as follows:

1. point estimate --a single valued estimate of a reliability parameter (Appendix B).
2. interval estimate --an estimate of an interval that is believed to contain the true value of the parameter (Appendix D).
3. distribution estimate --an estimate of the parameter of a reliability distribution (Appendix C).

<u>Point Estimates -- Appendix B</u> A point estimate of a parameter is a single value which is an estimate of the parameter. The most flexible estimation technique is the maximum likelihood estimator as discussed by Shooman in his Chapter 8 (23). In Appendix B, the maximum likelihood estimator approach is discussed in some detail. For example, the point estimate (MTBF) for the high voltage power supply at subgroup TASRA No. 362 is 363 hours based on 2901 test hours and 8 failures.

<u>Distribution Estimates -- Appendix C</u> Distribution

estimates are used when it is desired to estimate the probability distribution governing a particular reliability measure. This involves a two step approach; i.e.,

1. the form of the distribution must be determined from failure data,
2. the parameter that describes the distribution must be estimated.

To accomplish the above, the following goodness of fit test was selected. The Kolmogorov-Smirnov (K-S) test is an analytic procedure for testing goodness of fit, as discussed by Locks (14), Miller and Freund (16), and in the Army Materiel Command Pamphlet 706-198 (21). The procedure compares the observed distribution with a completely specified, hypothesized distribution and finds the maximum deviation between the cumulative distribution functions for the two. This deviation is then compared with a critical value $D_m$ that depends on a preselected level of statistical significance ($\alpha$). The K-S test is distribution free, and it can be used regardless of the failure distribution that the data are assumed to follow, provided the random variable is continuous. This test is good regardless of the sample size.

The reliability data obtained for the Rooftop Communication Terminal Group-30 were compared to an exponential distribution using the test described in Appendix C.

In summary, with significance level $\alpha$ set at .05 and a sample of 21 failures, the experienced deviation was less than the maximum deviation. Thus, it is reasonable to assume

that the sample came from a population with an exponential distribution. The results obtained are given in Table 18 of Appendix C.

<u>Interval Estimate -- Appendix D</u> A confidence interval is an interval estimate for which there is a known probability that the true value of the unknown parameter (e.g., MTBF) lies within a computed interval. This estimate is more useful than a point estimate because a much better idea is given of the uncertainty involved in the estimation process, as discussed by Shooman in Section 8.10 of Reference 23. Again the reliability data obtained for the Rooftop Communication Terminal Group-30 were used in the calculation of an interval estimate of MTBF for a sample of 21 failures at a 0.05 significance level, using the procedure described in Appendix D. As an example, the MTBF was calculated to be 95.7 hours with an upper confidence limit of 145.9 hours and a lower confidence limit of 62.05 hours for Group-30.

## CHAPTER 3

## SYSTEM DESCRIPTION

### SATCOM SYSTEM

The EHF and UHF SATCOM equipment designed for use in the LES 8 and 9 satellite test program was delivered in 1975. One set of EHF and UHF equipment was installed in a 4950th Flight Test Wing C-135 test aircraft (tail No. 662). A simplified block diagram of the SATCOM hardware is shown in Figure 2 (1).

EHF SATCOM Set The Airborne SATCOM Terminal (ASC-22) consists of a 1000 watt millimeter wave transmitter, a low noise receiving system, a steerable parabolic antenna, an antenna pointing system, a modulator and demodulator (MODEM), and input and output devices as discussed by C. K. Tsao in his technical report entitled "Ka-Band Satellite Communication Set AN/ASC-22" (27), and M. B. Cappa, et al., in the technical report entitled "Spread Spectrum Modem/Processor" (3). In addition to the capability of actively tracking the satellite, the SATCOM system has the capability of passive antenna pointing. An IBM π computer, part of the Computer Pointing System (OK-227), is used to compute the antenna pointing angle to the satellite from stored satellite ephemeris information and aircraft location/attitude information provided by an inertial navigation system (LTN51). These inputs allow the calculation of the pointing angles, the range, and the doppler or range rate, to the satellite as

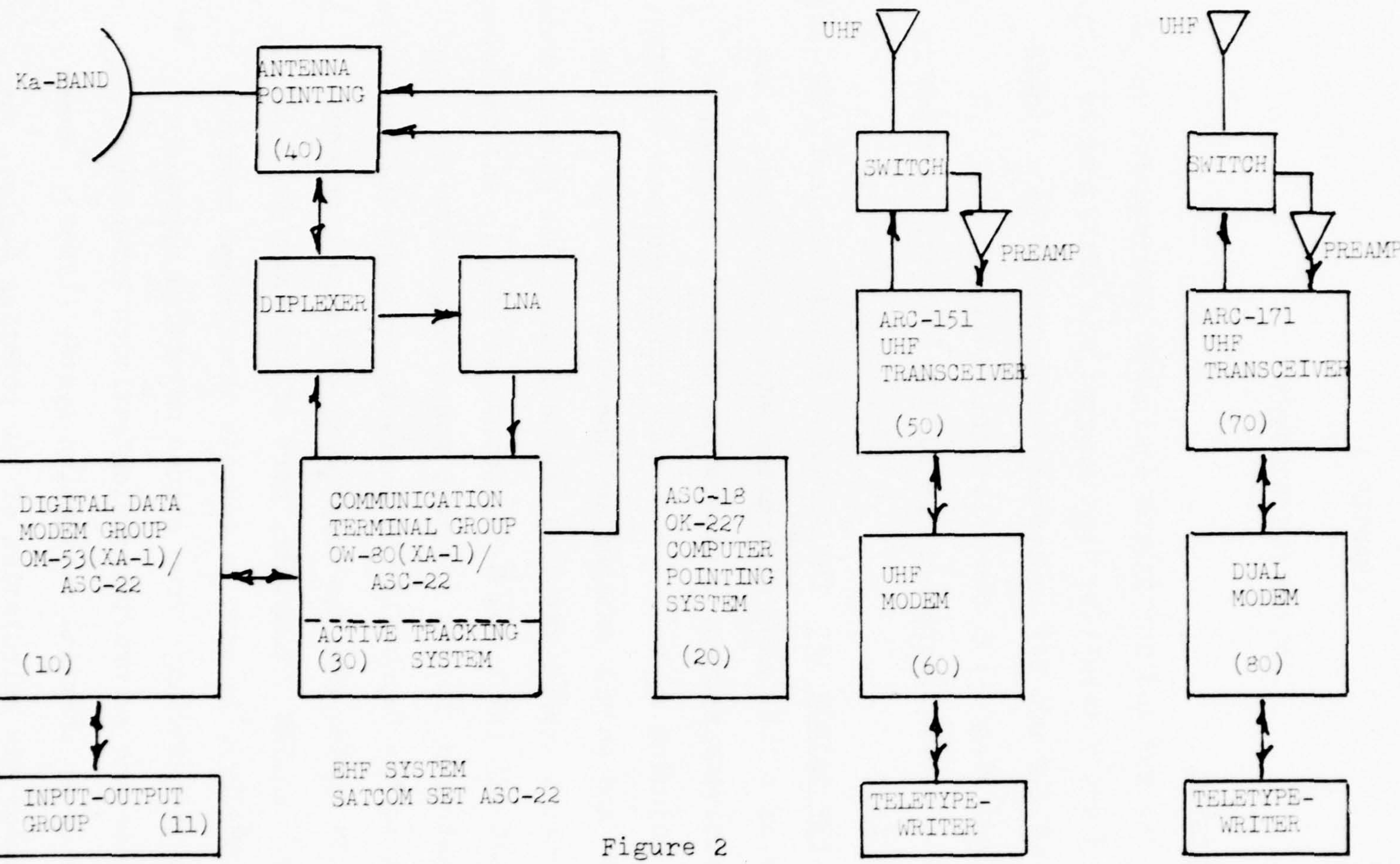



Figure 2

Aircraft and Rooftop Installation
Simplified Block Diagram

discussed by K.J. Allison, et al., in the technical report entitled "Airborne SHF Satellite Terminal Test Program" (2).

UHF SATCOM Set The UHF SATCOM system uses a UHF MODEM built by Linkabit Corp. and reported by I. M. Jacobs and K. Gilhousen in the technical report entitled "UHF AFSAT/SURVAT Dual Modem" (9). The UHF MODEM is physically located in the same rack as the Ka-Band MODEM. This MODEM interfaces with an ARC-151 UHF transceiver. The ARC-151 transceiver provides a 100 watt output transmit capability and operates through an omni-directional UHF antenna. The received signal passes through a transmit receive switch, into a preamplifier, and back to the ARC-151 transceiver for down-conversion. A second UHF SATCOM system aboard the test aircraft used an UHF "DUAL MODEM" system. The DUAL MODEM, was designed to work with the UHF modulation of LES 8 and 9 or by switch selection with UHF modulation of the AFSAT satellite. In either case, the modem feeds its signal to an ARC-171 UHF transceiver, and the 100 watt signal is transmitted through an omni-directional UHF antenna. The received signal is routed through a transmit receive switch to a preamplifier and to the ARC-171 transceiver.

Rooftop-Installation A complete complement of EHF and UHF SATCOM equipment was installed in AFAL's Building 620 rooftop facility, which was specifically built to house the SATCOM equipment. A simplified block diagram of the equipment is shown in Figure 2. The EHF modem, input and output devices,

transmitter and receiver, and low noise amplifier are identical to those described on test aircraft C-135/662. A 10-ft. parabolic antenna is used in the rooftop facility in place of the aircraft's 3-ft. antenna. An active tracking capability is provided in the receiver and transmitter rack. A computer pointing capability is provided by a computer located in the Communication System Evaluation Laboratory (CSEL) facility.

The UHF SATCOM equipment in the rooftop facility is identical to that described in Aircraft C-135/662. A UHF DUAL MODEM capability is also available in the rooftop facility.

## SATCOM SYSTEM RELIABILITY

This technical report discusses the operational reliability aspects of the EHF/UHF SATCOM terminals installed in the aircraft and the rooftop test facilities as described here. Each SATCOM SET is composed of subsystem groups as given in block diagrams in Figures 3 through 6. The groups, consisting of identifiable assemblies, are listed in Table 1. These assemblies have been assigned numerical designations in keeping with Tabular System Reliability Analysis (TASRA) designators established by Battelle Columbus Laboratories (BCL) for the SATCOM Reliability/Maintainability (R/M) model (4). These designators are used in the various block diagrams and tables throughout this report. The predicted MTBF values for the SATCOM SET subgroup elements, as given in Table 1, were provided by BCL as part of the AFAL's sponsored Ka-Band

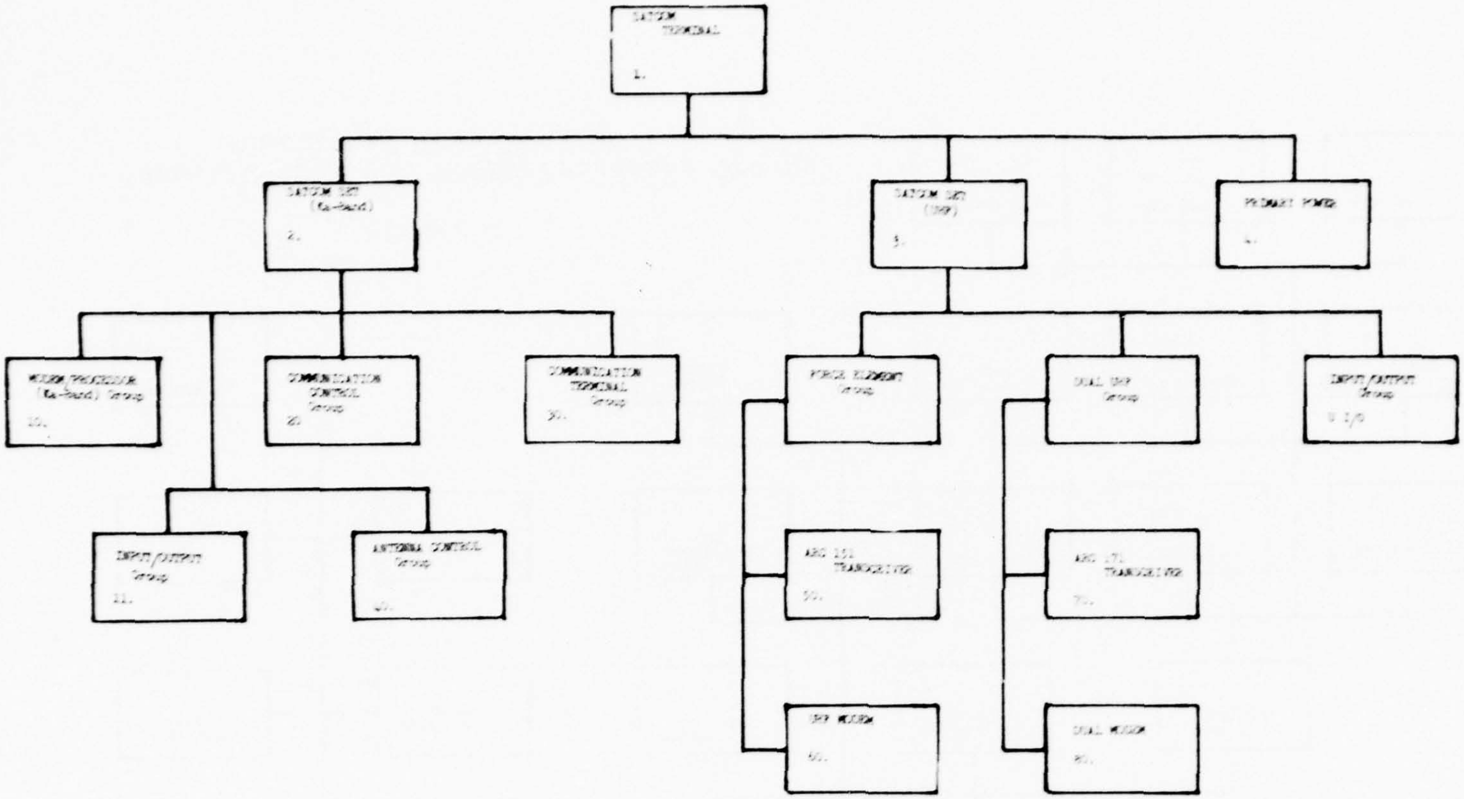



Figure 3

SATCOM Terminal
Functional Tree Diagram

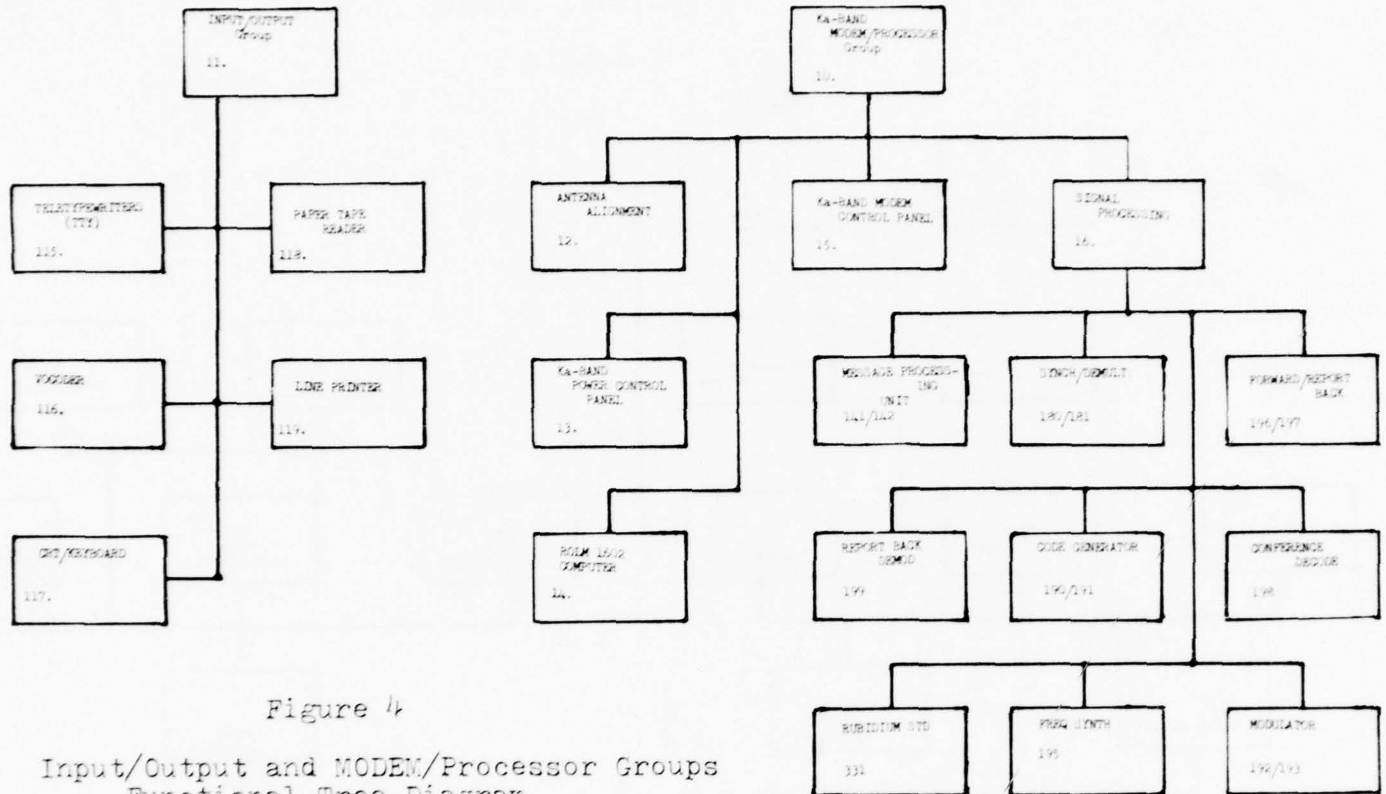



Figure 4

Input/Output and MODEM/Processor Groups
Functional Tree Diagram

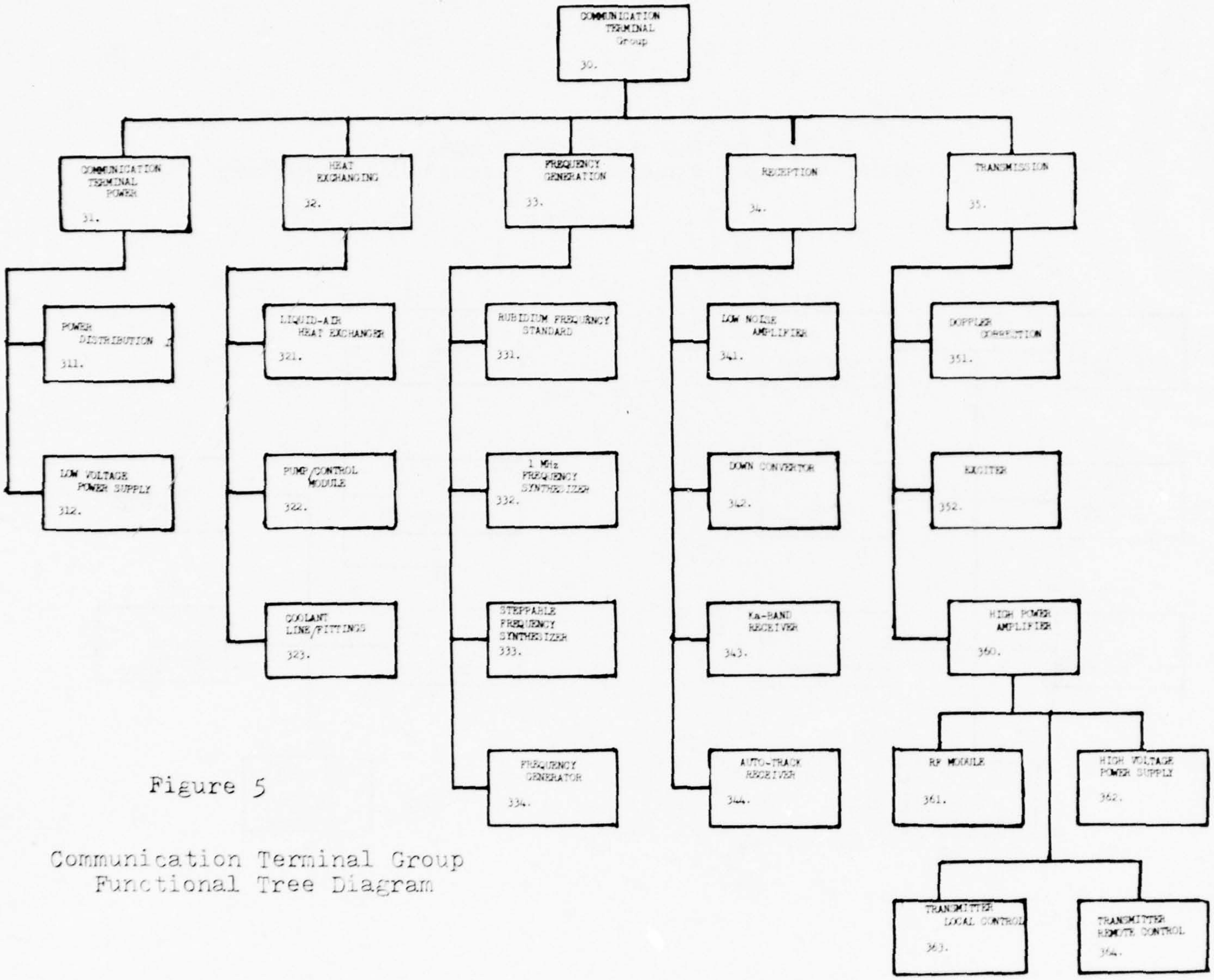



Figure 5

Communication Terminal Group
Functional Tree Diagram

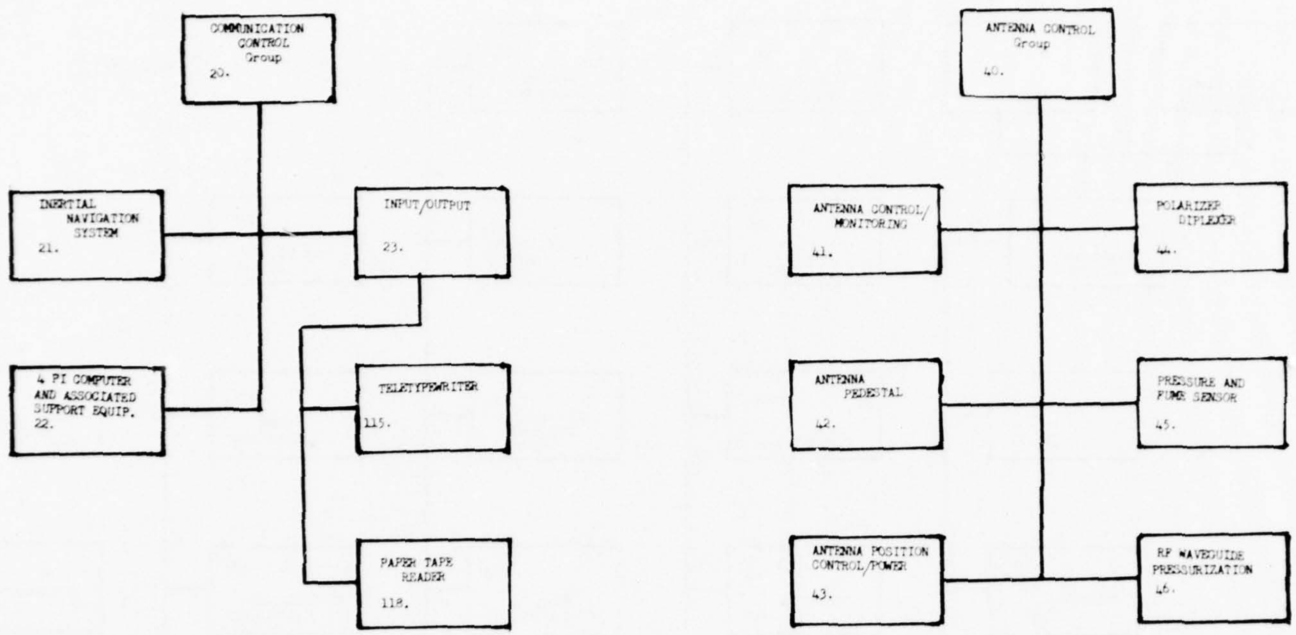



Figure 6

Communication Control and Antenna Control Groups
Functional Tree Diagram

Reliability Improvement Program under Contract F33615-75 C-1208. These predictions are based on the combined data estimates furnished to BCL by the EHF/UHF SARCOM SET equipment developers based on MIL-HDBK-217B and by AFAL based on field data collected during the EHF SATCOM SET test program (6).

Theoretical Estimates The theoretical system reliability model predictions are based on the equipment contractor's estimated bottom level component and module input data. These data were generated by the manufacturers using the methods of MIL-HDBK-217B to estimate the failure rate of electronic components and modules based on the number and types of parts used, the percentage of rated load at which each part is operated, the application of the equipment, etc. Although the reliability estimation methods of MIL-HDBK-217B are generally used for military equipment, such estimates will not detect inherently weak parts or conditions conducive to some failures, such as parts that are subject to unusual stresses from high transient voltages generated during switching, some types of poor design such as striving to achieve too high a gain in a single stage of amplification, improper interpretation of the handbook guidelines, etc. These types of failures will often become evident only during equipment operation and use.

Field Data Estimates The field data estimates are calculated from field experience on the existing SATCOM SET (Appendix B). The Bayesian method provided an approach for combining the reliability data obtained through experience

(flight test) with theoretical estimates. An example in the next paragraph shows the approach used.

<u>Combined Estimates</u> Drennan, on Page B-3 of Reference 6, discusses this approach for determining the combined estimates based on two sets of data, the theoretical prediction and the field experience. The procedure selected by BCL for implementing a Bayesian approach for adjusting a predicted failure rate (1/MTBF) with field experience data includes the assumption that 10,000 hours of test time is added to the flight test time of 3900 hours. Knowing the predicted failure rate ($\lambda_p$) and the assumed operating test time of 10,000 hours the predicted number of failures can be determined. In the same manner the field experienced failure rate ($\lambda_f$) can be determined based on the number of failures experienced and number of total operating hours. As an example, for the subgroup TASRA No. 362, the combined estimate ($1/\lambda_c$) is determined.

$$\lambda_p = 1/3955 = 2.53 \text{ failures}/10{,}000 \text{ hours},$$
$$\lambda_f = 1/216 = 18.1 \text{ failures}/3{,}900 \text{ hours},$$
$$\lambda_c = (2.53 + 18.1)/(10{,}000 + 3{,}000)$$
$$= 20.6/13{,}900 \approx 1 \text{ failure}/675 \text{ hours}$$

The above is based on the data given in the Interim Special Technical report prepared by BCL (6). The combined estimates (Table 1) were used in calculating the predicted MTBF for comparison to the observed MTBF for the EHF SATCOM SET. The various devices in the Input/Output group, as listed in Table 1, were used in various combinations at various times during each test. Therefore, a nominal MTBF value of 1000 hours was

TABLE 1 SATCOM SET PREDICTED MTBF ITEM LISTING

| TASRA Nr. | TITLE | PREDICTED MTBF hrs |
|---|---|---|
| 1 | SATCOM TERMINAL | 35 |
| 2 | SATCOM SET (Ka-BAND) | 38 |
| 10 | MODEM-PROCESSOR GROUP | 107 |
| 12 | ANTENNA ALIGNMENT | 11980 |
| 13 | POWER CONTROL PANEL | 15664 |
| 14 | ROLM 1602 COMPUTER | 981 |
| 15 | Ka-BAND CONTROL PANEL | 3054 |
| 141 --- | MESSAGE PROCESSING UNITS | 506 |
| 180 --- | SYNCH-DEMUX UNITS | 324 |
| 190 --- | CODE GENERATOR | 1993 |
| 195 | FREQ SYNTH | 1500 |
| 199 | REPORT BACK DEMOD | 1830 |
| 196 --- | FORWARD-REPORT BACK | 17497 |
| 198 | CONFERENCE DECODE | 5582 |
| 192 --- | MODULATOR | 8374 |
| 11 | INPUT-OUTPUT GROUP | 1000 |
| 115 | TELETYPEWRITER | 1500 |
| 116 | VOCODER | 2500 |
| 117 | CRT-KEYBOARD | 2000 |
| 118 | PAPER TAPE READER | 1000 |
| 119 | LINE PRINTER | 2000 |
| 20 | COMMUNICATION CONTROL GROUP | 158 |
| 21 | INERTIAL NAVIGATION SYSTEM | 750 |
| 22 | COMMUNICATION CONTROL COMPUTER | 300 |
| 23 | INPUT-OUTPUT DEVICES | 1000 |
| 30 | COMMUNICATION TERMINAL GROUP | 129 |
| 311 | POWER DISTRIBUTION | 2713 |
| 312 | LOW VOLTAGE POWER SUPPLY | 4197 |
| 321 | LIQUID-AIR HEAT EXCHANGER | 100000+ |
| 322 | PUMP-CONTROL MODULE | 1939 |
| 323 | COOLANT LINES-FITTINGS | 100000+ |
| 331 | RUBIDIUM STANDARD | 1405 |
| 332 | 1 MHz FREQ SYNTH | 6537 |
| 333 | STEPPABLE FREQ SYNTH | 24732 |
| 334 | FREQ GENERATOR | 2121 |
| 341 | LOW NOISE AMPLIFIER | 1548 |
| 342 | DOWN CONVERTOR | 4570 |
| 343 | RECEIVER | 100000+ |
| 344 | AUTO TRACK RECEIVER | 3028 |

TABLE 1 SATCOM SET PREDICTED MTBF ITEM LISTING (Continued)

| TASRA Nr. | TITLE | PREDICTED MTBF hrs |
|---|---|---|
| 351 | DOPPLER CORRECTOR | 2555 |
| 352 | EXCITER | 4436 |
| 361 | RF MODULE (TWT) | 949 |
| 362 | HIGH VOLTAGE POWER SUPPLY | 675 |
| 363 | TRANSMITTER LOCAL CONTROL | 855 |
| 364 | TRANSMITTER REMOTE CONTROL | 27065 |
| 40 | ANTENNA CONTROL GROUP | 808 |
| 41 | ANTENNA CONTROL MONITOR | 2154 |
| 42 | ANTENNA PEDESTAL | 21370 |
| 43 | ANTENNA POSITION CONTROL-POWER | 11840 |
| 44 | POLARIZER-DIPLEXER | 2301 |
| 45 | PRESSURE AND FUME SENSOR | 28560 |
| 46 | RF WAVEGUIDE PRESSURE | 5831 |
| 3 | SATCOM SET (UHF) | 517 |
| U-I/O | INPUT-OUTPUT DEVICES | 2000 |
| 50 | ARC-151 TRANSCEIVER | 1278 |
| 60 | UHF MODEM | 1476 |
| 70 | ARC-171 TRANSCEIVER | 1300 |
| 80 | DUAL MODEM | 1500 |
| 4 | PRIMARY POWER | 1000 |

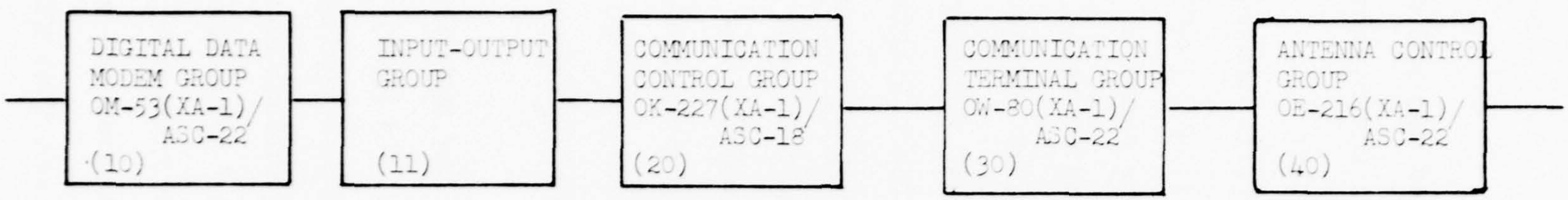
assumed for the Input/Output Group.

SATCOM SYSTEM RELIABILITY MODELS

The SATCOM SET (EHF Band) was modeled for reliability prediction purposes into Reliability Models A and B, but the SATCOM SET (UHF) was modeled as in Model A only.

Series Chain Operation Model A, as illustrated in Figure 7, assumes that all terminal equipment must function properly for a successful mission. Model A is based on the approach that all system elements are in a series chain so that any element failure will result in a system outage. Also, for the SATCOM SET (UHF) this applies to either the ARC-151 or ARC-171 transceiver with MODEM separately. The reliability model for each of the groups considers its respective subgroup element as connected in series based on component repair or replacement as discussed in Appendixes B and D. The mathematical models used in calculating the group's reliability are given in Table 2. Gerald H. Sandler in his text entitled "System Reliability Engineering" discusses reliability modeling concepts (22).

Minimum System Operation To obtain the apparent reliability for the minimum system operation, the Model A as shown in Figure 7 was restructured to the Model B configuration shown in Figure 8. This simplifies the computational Model to a manageable form. The equation shown for the redundant elements covers the case of two parallel, active independent elements with unlike failure rates. To illustrate, the MTBF for this case is derived below. It can be shown that MTBF is




$$R_2 = R_{10}R_{11}R_{20}R_{30}R_{40}$$

$$\lambda_2 = \lambda_{10}+\lambda_{11}+\lambda_{20}+\lambda_{30}+\lambda_{40}$$

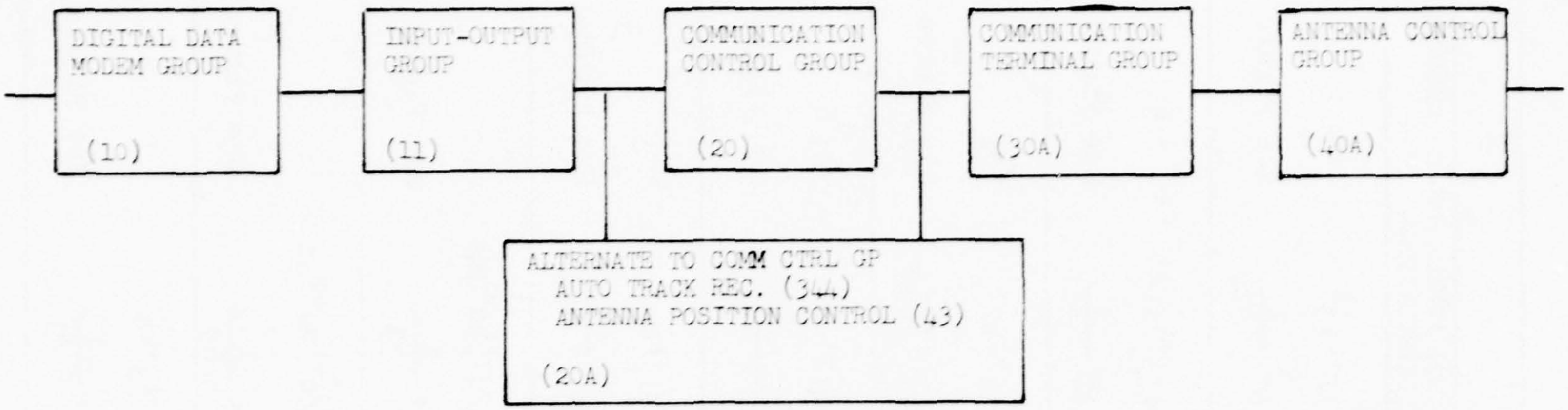
$$MTBF_2 = \frac{1}{\lambda_2}$$

Figure 7

SATCOM Set (Ka-Band)
Reliability Model A

TABLE 2 RELIABILITY MODELS

| TASRA Nr. | SET or GROUP | MATHEMATICAL MODELS FOR (i) ELEMENTAL LEVEL CALCULATIONS |
|---|---|---|
| (10) | DIGITAL DATA MODEM GROUP | $\lambda_{10}=\lambda_{12}+\lambda_{13}+ \cdots +\lambda_i$<br>$MTBF_{10}=\frac{1}{\lambda_{10}}$ See Figure 4 |
| (11) | INPUT-OUTPUT GROUP | $\lambda_{11}=\lambda_{115}+\lambda_{116}+ \cdots +\lambda_i$<br>$MTBF_{11}=\frac{1}{\lambda_{11}}$ See Figure 4 |
| (20) | COMMUNICATION CONTROL GROUP | $\lambda_{20}=\lambda_{21}+\lambda_{22}+ \cdots +\lambda_i$<br>$MTBF_{20}=\frac{1}{\lambda_{20}}$ See Figure 6 |
| (30) | COMMUNICATION TERMINAL GROUP | $\lambda_{30}=\lambda_{31}+\lambda_{32}+ \cdots +\lambda_i$<br>$MTBF_{30}=\frac{1}{\lambda_{30}}$ See Figure 5 |
| (40) | ANTENNA CONTROL GROUP | $\lambda_{40}=\lambda_{41}+\lambda_{42}+ \cdots +\lambda_i$<br>$MTBF_{40}=\frac{1}{\lambda_{40}}$ See Figure 6 |
| (3-S) | UHF SATCOM SET SINGLE MODEM | $\lambda_3=\lambda_{I/O}+\lambda_{50}+\lambda_{60}$<br>$MTBF_3=\frac{1}{\lambda_3}$ See Figure 3 |
| (3-D) | UHF SATCOM SET DUAL MODEM | $\lambda_3=\lambda_{I/O}+\lambda_{70}+\lambda_{80}$<br>$MTBF_3=\frac{1}{\lambda_3}$ See Figure 3 |
| (1) | SATCOM SYSTEM less SATELLITE | $\lambda_1=\lambda_2+\lambda_3+\lambda_4$<br>$MTBF_1=\frac{1}{\lambda_1}$ See Figure 3 |




$$R_2 = R_{10}R_{11}(R_{20A}+R_{20}-(R_{20A}R_{20}))R_{30A}R_{40A}$$

$$\lambda_2 = \lambda_{10}+\lambda_{11}+\frac{1}{\frac{1}{\lambda_{20A}}+\frac{1}{\lambda_{20}}-\frac{1}{\lambda_{20A}+\lambda_{20}}}+\lambda_{30A}+\lambda_{40A}$$

$$MTBF_2 = \frac{1}{\lambda_2}$$

Figure 8

SATCOM Set (Ka-Band)
Reliability Model B

related to the Reliability Function by:

$$MTBF = \int_0^\infty R(t)dt$$

For parallel elements the probability of either or both surviving is derived from probability theory as:

$$R(t) = R_a(t) + R_b(t) - R_a(t)R_b(t).$$

It is assumed that the probability density function is an exponential distribution as discussed by Shooman (23). Then

$$f(t) = (1/\theta)\exp(-(t/\theta)), \quad t \geq 0, \theta > 0$$
$$= \lambda \exp(-\lambda t), \quad \lambda = 1/\theta$$

where the

$$\text{Mean} = \theta$$
$$\text{Variance} = \theta^2$$

and the probability of no failures, R(t), in the interval (0 to t) is given by

$$R(t) = 1 - F(t)$$
$$= \exp(-\lambda t).$$

Therefore

$$R_a(t) = \exp(-\lambda_a t)$$
$$R_b(t) = \exp(-\lambda_b t)$$

where $\lambda_a$ and $\lambda_b$ are element failure rates,

and

$$MTBF = \int_0^\infty (\exp(-\lambda_a t) + \exp(-\lambda_b t) - \exp(-(\lambda_a+\lambda_b)t))dt$$
$$= (1/\lambda_a) + (1/\lambda_b) - (1/(\lambda_a+\lambda_b)).$$

## CHAPTER 4

## DATA ACQUISITION

### TEST PLAN

The reliability of the EHF SATCOM set and the UHF SATCOM set was evaluated for the entire flight test program. Failure reports were obtained on all malfunctions which affected system operation. This was accomplished with minimum interference to the ongoing test program. These reports were tabulated, and a determination was made as to whether the failure was relevant or non-relevant. The failure report data were tabulated and plotted in terms of the observed monthly and cumulative Mean Time to Failure values as given in Appendix A.

The overal flight test plan addressed such questions as:

1. how close to theoretical do the UHF and EHF systems perform in both a jamming and non-jamming environment?
2. what is the reliability and maintainability performance of the aircraft and rooftop SATCOM TERMINAL installations?

The objective of the flight test program was to demonstrate the feasibility of an EHF airborne satellite communication system operating in a hostle dynamic jamming environment as discussed by James Miller in his flight test

report entitled; "SURSATCOM (Ka-Band Flight Test Report" (17). AFAL, with the support from other Department of Defense agencies, measured the performance of the EHF and EHF SATCOM system under various propagation and flight conditions. The results will provide a base line for future engineering development or pre-production models of the EHF SATCOM system.

Technical, reliability, or human engineering deficiencies were recorded during the test program and documented so that corrective action can be taken during follow-on development programs. The test plan included data acquisition and data reduction phases in preparation for the analysis phase.

DATA COLLECTION

A data collection procedure was implemented to provide data inputs for the following factors in order to accomplish the goals given in Chapter 1.

1. System Mean Time Between Occurrence (MTBO)
2. System Mean Time Between Failures (MTBF)
3. Group Mean Time Between Occurrence (MTBO)
4. Group Mean Time Between Failures (MTBF)

The data acquisition report forms (format prepared by BCL) consisted of a malfunction report and an event log. A SATCOM system malfunction report contained spaces for group level, major module and submodule level information. This included malfunction description, cause and corrective action, plus the elapsed time indicator readings and system location. A SATCOM system event log contained time of day,

elapsed time indicator at location and at group level, plus a malfunction report number and event remarks.

The above two data report forms were used by the "SATCOM SET" field engineers and technicians in the recording of observed equipment malfunctions during the test program maintenance and repair at the aircraft and the rooftop test locations.

DATA REDUCTION

The raw data were reviewed in detail and transferred to the SATCOM system malfunction event analysis sheet, which provided space to record a standardized event description, the event effect on the system, the event cause, the maintenance action, the maintenance time to repair, and notes. Space was also provided for recording the month, the assessed equipment identification number, the event sequence number, and the operating hours for each component in the equipment group. The event analysis sheets, which formed the basis for the data presented herein, were used to cull out non-relevant failures from the observed malfunctions.

In the event analysis sheets, each event is classified into one of two event description categories of equipment failure and equipment malfunction. The first category is self-explanatory, and the second category covers those cases when the equipment is not available for inclusion in the system operation configuration due to unresolved problems.

The "event effect" classification addresses the loss

of the system, the partial loss of system, or no loss to system. These categories provided the basis for evaluating the effect of each failure on system availability and assisted in clarifying those problems which are system relevant for both the aircraft and the rooftop environments.

The "event cause" classification provided the following four standardized categories: module or part failure, external cause for intermittent failure, unknown or unable to varify failure, and the installation of design modification.

The "maintenance action" classification provides these three following categories:

1. rectify or replace module;
2. remove and replace part; and
3. troubleshoot action;

which afforded a quick look at the maintenance action initiated as a result of the occurrence of each event.

Information contained in some of the event analysis reports indicated that no failures occurred at the element or subgroup levels. Therefore, a statistical method was formulated to provide the MTBF estimate at a 60% confidence level. The approach taken was discussed by Allison, et la., in the SHF Terminal Test Report (2). This approach is based on the determination of a one sided confidence interval estimate for a parameter with an exponential distribution, assuming that the tests are stopped after a certain number of test hours have been accumulated.

The formula for this confidence interval employs the $X^2(p,d)$ (Chi-Square) distribution as discussed by Von Alven (28), where p is the function of the confidence coefficient $\alpha$ and d is the degrees of freedom. For a one sided (lower limit) confidence level with a fixed total accumulated time period T and with no failures, r = 0, the equation is

$$\theta = (2T/X^2(\alpha, 2r+2), \infty).$$

For example, let r = 0 at a confidence level of 60% resulting in $X^2(0.6,2)$ approximately equal to 0.707 as taken from the $X^2$(Chi-Square) distribution tables.

Therefore, the lower limit MTBF ($\theta_L$) at r = zero with a confidence level of 60% is

$$\theta_L = 2T/0.707 = 2.829T.$$

Thus, there is a 60% probability that the true MTBF is included within the lower limit of $\theta_L$ and infinity for zero failures. This is the basis for calculating MTBF values in Tables 3 through 8.

The reliability analysis for both systems Models A and B and each group provides two measures of system performance.

1. Mean Time Between Incidents (Malfunction).
2. Mean Time Between Failures (MTBF).

Both of these measures of system performance are quantified in Tables 3 through 8 of Chapter 5 and the appropriate tables and plotted graphs in Appendix A.

## CHAPTER 5

## DATA ANALYSIS

### INTRODUCTION

The system reliability analysis was based upon reported equipment malfunctions from January of 1976 to September of 1977, during the ongoing EHF/UHF test program (7). The data were collected, tabulated, and plotted from both the aircraft and rooftop locations and included a total of 6480 operating hours and 322 equipment malfunction reports. These tabulated and plotted data are presented in Appendix A. Care must be exercised in interpreting the results since these results are fundamentally determined by the input data. A basic concern throughout this analysis has been, "How realistic are the available mean time between failures (MTBF) input data?" The malfunctions that have been experienced to date are generally of the type that can be experienced in an operational environment, such as human error, random part failure, cabling problems, and malfunction induced by incorrect operation of the ancillary equipment.

### EVENT ANALYSIS

All events reported on the Event Analysis Sheets were used in the calculation of the Mean Time Between Incidents (malfunction) statistics as given in the tabulations and plots in Appendix A. The following guidelines, described in the SHF Satellite Test Report (2), were used in determining which

events were non-relevant in the calculation of the Mean Time Between Failures at the elemental or subgroup level:

1. events reported as problems for which an independent failure had previously been identified;
2. secondary failures where a primary failure was indicated;
3. failures or intermittent failures due to external causes and those attributed to random or inexplicable interference which caused a short term outage;
4. failures in ancillary or support equipment or interconnections;
5. failures attributed to operator error; and
6. removal and replacement of a module or other maintenance actions required to incorporate design changes into the system.

In an operational test program environment, the inherent reliability is generally degraded by one or more of the following factors:

1. installation complexity, interfaces and environment;
2. variation in operator capability and knowledge of the equipment;
3. substandard maintenance and repair practices;
4. residual design and manufacturing errors;

not detected and corrected due to limited production;

5. ancillary equipment; and

6. human engineering factors.

Since these factors are interactive and contain a human variable, a precise value cannot be readily determined for the operational reliability of a system. An evaluation of the expected degradation due to these factors can usually be made by heuristic means based upon past experience with like equipment under similar installation and operating conditions. Using this approach, it is the opinion of the writer a potential growth to a MTBF of 60 hours appears realistic, but any increases in MTBF beyond this level may be obtainable only by the expenditure of considerable effort. Also, design improvements in the RF module-361, high voltage power supply-362, or SYNCH/DEMUX-180/181 could provide the highest reliability payoff.

It should also be noted that there was no clear demarcation between system mission operating time and the operating time of the equipment devoted to checkout, maintenance, and repair. The total operating time shown for each equipment group containing these additional hours will tend to enhance the reported reliability during the initial reporting periods. However, as the total mission time increases, these factors will become less and less significant for the overall evaluation.

The malfunctions reports did not contain sufficient detail to indicate simultaneous failures of redundant elements which would cause a complete system outage, leading to the following two assumptions:

1. simultaneous failures did not occur (observed failure rate). This condition reduces the failure rate of the redundant block to zero; and
2. simultaneous failures did occur (estimated failure rate). To simulate this condition, a 60% confidence level was used to evaluate the failure rate of the individual components or groups for which zero failure was reported.

This represents a statistical anomaly for the groups wherein no malfunctions were reported. Reference is made to discussion on Pages 39 and 40, and to Allison, et la. (2).

Since different operating times have been logged by each group in the system, the cumulative MTBI (malfunction) and MTBF (actual failure) for the Model A system were calculated by using the mathematical model shown in Figure 7. The MTBF for each of the groups was calculated from the group models given in Table 2. The resulting system Model A MTBF values are presented in Tables 3 through 6. The system's estimated MTBF is shown in Table 1. The resulting MTBF values for both the observed (actual) and the estimated (60% confidence level) cases are shown in Tables 3, 4, 5, and 6, and bar graphs in Figures 9 through 14. The tables and plots

TABLE 3 MTBF SUMMARY FOR THE TOTAL SYSTEM

| TASRA Nr. | TITLE | AIRCRAFT DATA Operating Hours | Failures | MTBF | ROOFTOP DATA Operating Hours | Failures | MTBF |
|---|---|---|---|---|---|---|---|
| 1 | SATCOM TERMINAL | 3095 | 135 | 18 | 3056 | 82 | 34 |
| 2 | SATCOM SET (EHF) | 3095 | 100 | 23 | 3056 | 71 | 42 |
| 10 | MODEM-PROCESSOR Grp | 2207 | 36 | 61 | 3056 | 17 | 147 |
| 11 | INPUT-OUTPUT Grp | 2207 | 3 | 595 | 3056 | 9 | 327 |
| 20 | COMM CONTROL Grp | 1497 | 13 | 129 | ---- | --- | ---- |
| 30 | COMM TERM Grp | 2901 | 44 | 65 | 3385 | 37 | 87 |
| 40 | ANTENNA CONTROL Grp | 2901 | 4 | 616 | 3385 | 8 | 389 |
| 3 | SATCOM SET (UHF) | 3082 | 35 | 90 | 2501 | 13 | 193 |
| UHF | INPUT-OUTPUT Grp | 3082 | 5 | 616 | 2501 | 2 | 1251 |
| 50 | ARC-151 TRANSCEIVER | 1301 | 3 | 434 | 2501 | 8 | 313 |
| 60 | UHF MODEM | 1301 | 8 | 163 | 2501 | 3 | 834 |
| 70 | ARC-171 TRANSCEIVER | 1781 | 9 | 198 | ---- | --- | ---- |
| 80 | DUAL MODEM | 1781 | 10 | 178 | ---- | --- | ---- |
| 4 | PRIMARY POWER | 3095 | # | 8756 | 3385 | # | 9576 |

\# Computed at the 60% Confidence level, $MTBF = 2T/X^2(2r+2)(.6)$

$= 2.829\ T$

TABLE 4 MTBF SUMMARY FOR GROUP 10

| TASRA Nr. | TITLE | AIRCRAFT DATA Operating Hours | Failures | MTBF | ROOFTOP DATA Operating Hours | Failures | MTBF |
|---|---|---|---|---|---|---|---|
| 10 | MODEM-PROCESSOR Grp | 2207 | 36 | 61 | 3056 | 17 | 147 |
| 12 | ANTENNA ALIGNMENT | " | 1 | 2207 | " | # | 8645 |
| 13 | POWER CONTROL PANEL | " | 2 | 1104 | " | # | 8645 |
| 14 | ROLM 1602 COMPUTER | " | 5 | 441 | " | 4 | 764 |
| 15 | Ka-BAND MODEM CONT | " | 6 | 368 | " | 2 | 1528 |
| 141-- | MESSAGE PROCESSING | " | 1 | 2207 | " | # | 8645 |
| 180-- | SYNCH-DEMUX | " | 12 | 184 | " | 4 | 764 |
| 190-- | CODE GENERATOR | " | 1 | 2207 | " | # | 8645 |
| 195 | FREQ SYNTH | " | 2 | 1104 | " | # | 8645 |
| 331 | RUBIDIUM STANDARD | " | 1 | 2207 | " | 1 | 3056 |
| 199 | REPORT BACK DEMOD | " | 2 | 1104 | " | 3 | 1019 |
| 196-- | FORWARD-REPORT BACK | " | 2 | 1104 | " | 1 | 3056 |
| 198 | CONFERENCE DECODE | " | 1 | 2207 | " | 3 | 1019 |
| 192-- | MODULATOR | " | # | 6244 | " | 1 | 3056 |
| 11 | INPUT-OUTPUT Grp | 2207 | 3 | 595 | 3056 | 9 | 327 |
| 115 | TELETYPEWRITER | " | 1 | 2207 | " | 4 | 764 |
| 116 | VOCODER | " | # | 6244 | " | 2 | 1528 |
| 117 | CRT-KEYBOARD | " | 1 | 2207 | " | 2 | 1528 |
| 118 | PAPER TAPE READER | " | 1 | 2207 | " | # | 8645 |
| 119 | LINE PRINTER | " | # | 6244 | " | 1 | 3056 |

# Computed at the 60% Confidence level.

TABLE 5 MTBF SUMMARY FOR GROUPS 20 and 40

| TASRA Nr. | TITLE | AIRCRAFT DATA Operating Hours | Failures | MTBF | ROOFTOP DATA Operating Hours | Failures | MTBF |
|---|---|---|---|---|---|---|---|
| 20 | COMM CONTROL Grp | 1497 | 13 | 156 | ---- | --- | ---- |
| 21 | INERTIAL NAV SYS | 1350 | 1 | 1350 | ---- | --- | ---- |
| 22 | COMM CONT COMP | 1376 | 5 | 275 | ---- | --- | ---- |
| 23 | INPUT-OUTPUT DEVICES | 1497 | 3 | 499 | ---- | --- | ---- |
| 40 | ANTENNA CONTROL Grp | 2901 | 4 | 616 | 3385 | 8 | 389 |
| 41 | ANTENNA CONTROL MONI- | " | 1 | 2901 | " | 5 | 677 |
| 42 | ANTENNA PEDESTAL | " | # | 8207 | " | 1 | 3385 |
| 43 | ANT.POSITION CONT-POW | " | 1 | 2901 | " | 1 | 3385 |
| 44 | POLARIZER-DIPLEXER | " | # | 8207 | " | # | 9576 |
| 45 | PRESSURE-FUME SENSOR | " | 1 | 2901 | " | # | 9576 |
| 46 | RFWAVEGUIDE PRESSURE | " | 1 | 2901 | " | 1 | 3385 |

# Computed at the 60% Confidence level.

TABLE 6 MTBF SUMMARY FOR GROUP 30

| TASRA Nr. | TITLE | AIRCRAFT DATA Operating Hours | Failures | MTBF | ROOFTOP DATA Operating Hours | Failures | MTBF |
|---|---|---|---|---|---|---|---|
| 30 | COMM TERMINAL Grp | 2901 | 44 | 65 | 3385 | 37 | 86 |
| 311 | POWER DISTRIBUTION | " | 1 | 2901 | " | 1 | 3385 |
| 312 | LOW VOLT-POWER SUPPLY | " | # | 8207 | " | 1 | 3385 |
| 321 | LIQUID-AIR HEAT EXCH | " | 1 | 2901 | " | 3 | 1128 |
| 322 | PUMP-CONTROL MODULE | " | 2 | 1451 | " | 3 | 1128 |
| 323 | COOLANT LINE-FITTING | " | # | 8207 | " | 2 | 1693 |
| 331 | RUBIDIUM STANDARD | " | 4 | 725 | " | # | 9576 |
| 332 | 1 MHz FREQ SYNTH | " | # | 8207 | " | # | 9576 |
| 333 | STEPPABLE FREQ SYNTH | " | # | 8207 | " | # | 9576 |
| 334 | FREQ GENERATOR | " | # | 8207 | " | 3 | 1128 |
| 341 | LOW NOISE AMPLIFIER | " | 2 | 1451 | " | 5 | 677 |
| 342 | DOWN CONVERTOR | " | 2 | 1451 | " | # | 9576 |
| 343 | RECEIVER | " | 2 | 1451 | " | 2 | 1693 |
| 344 | AUTO TRACK RECEIVER | " | 1 | 2901 | " | # | 9576 |
| 351 | DOPPLER CORRECTOR | " | 2 | 1451 | " | 1 | 3385 |
| 352 | EXCITER | " | 3 | 967 | " | 3 | 1128 |
| 361 | RF MODULE (TWT) | " | 8 | 363 | " | 7 | 484 |
| 362 | HIGH VOLT-POWER SUPPLY | | 8 | 363 | " | 2 | 1693 |
| 363 | XMITTER LOCAL CONT | " | 6 | 434 | " | 4 | 846 |
| 364 | XMITTER REMOTE CONTR | " | # | 8207 | " | # | 9576 |

\# Computed at the 60% Confidence level.

presented in Appendix A provided a breakdown of the system MTBF into the individual groups.

TOTAL SYSTEM

SATCOM Terminal - TASRA No. 1   A review of Table 3 and Figure 9 shows that each installation was operated for nearly the same number of total hours and with basically the same type of equipment in each location. The reliability at the rooftop location is nearly twice that experienced on the aircraft location. In spite of the two totally different environments, degradation for a Laboratory or operational test system was not as different as anticipated, because of periodic equipment interchanges for maintenance support purposes during the flight test program.

SATCOM Set - TASRA No. 2   A like comparison was made for the SATCOM SET (Ka-Band) with the same resulting comments as given above, except for reliability of the antenna control group reliability. The difference here was the use of a 10-ft. dish on the rooftop installation and a 3-ft. dish in the aircraft, causing a greater need to debug the larger installation.

SATCOM Set - TASRA No. 3   In the SATCOM Set (UHF), the equipment was generally operated in either location; however, a particular serial number single MODEM (60) and ARC-151 transceiver (50) were generally assigned to each location.

Prime Power - TASRA No. 4   Note that in Table 3

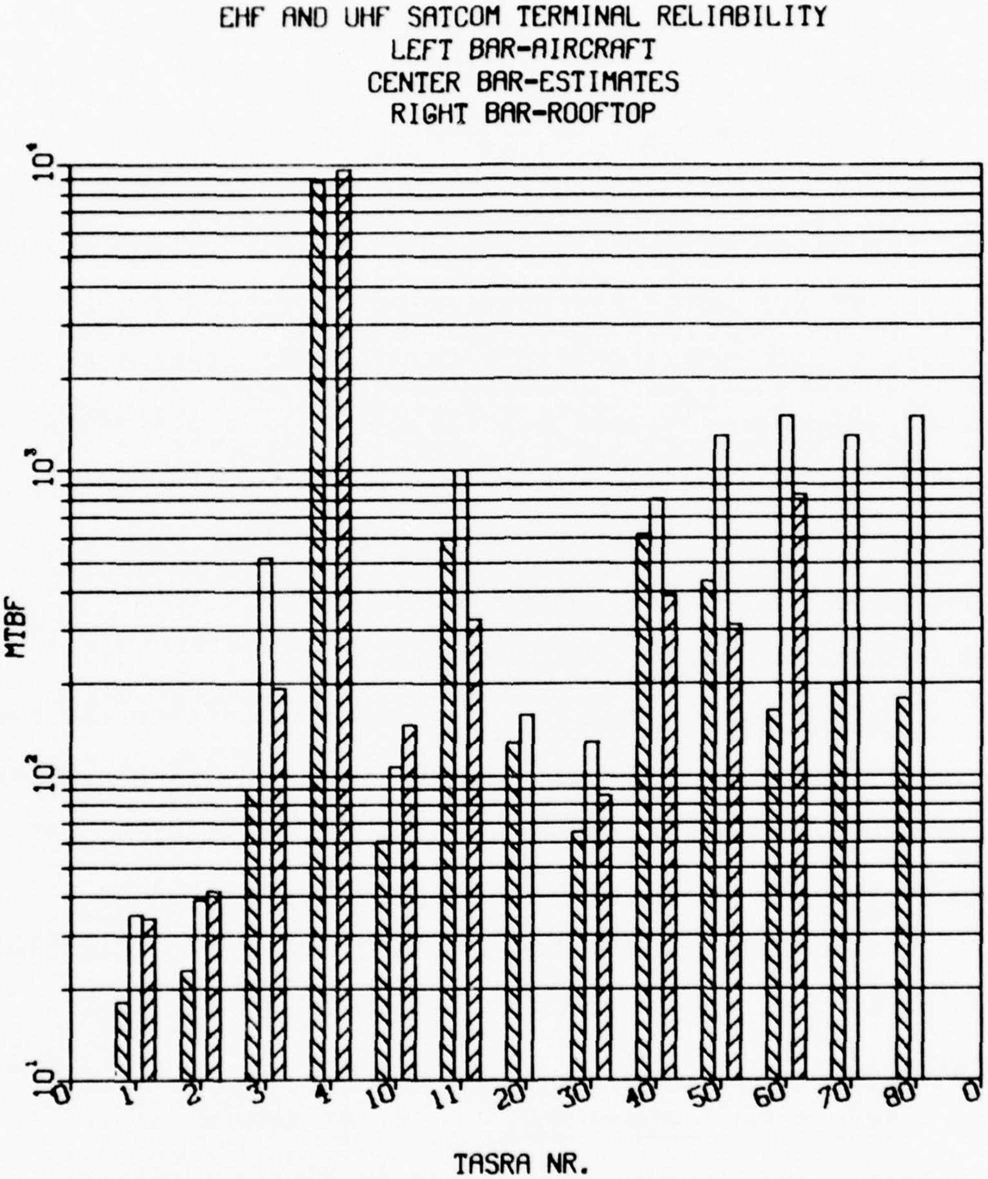



Figure 9

SATCOM Terminal Bar Graph

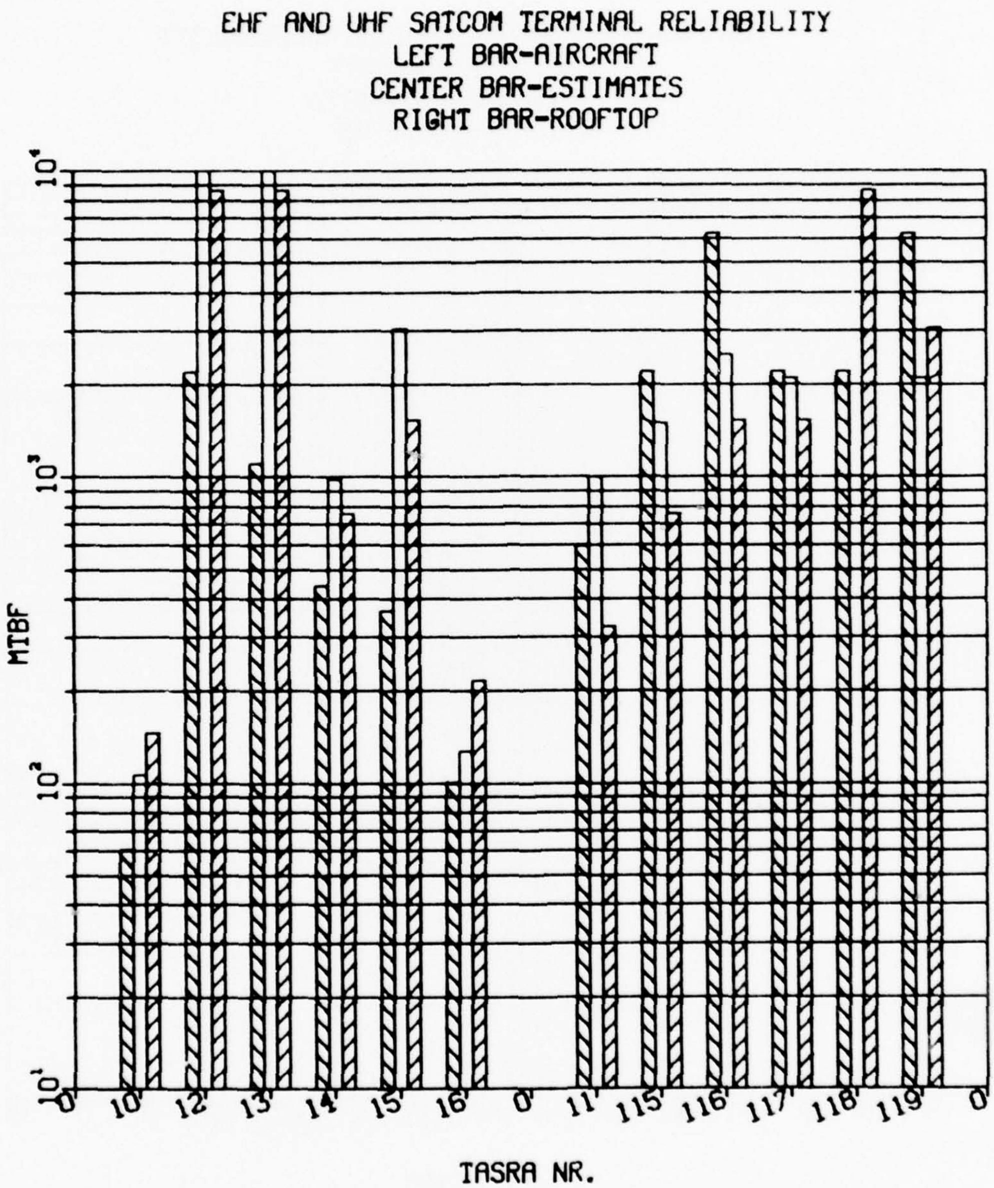



Figure 10

MODEM/Processor and Input/Output Groups

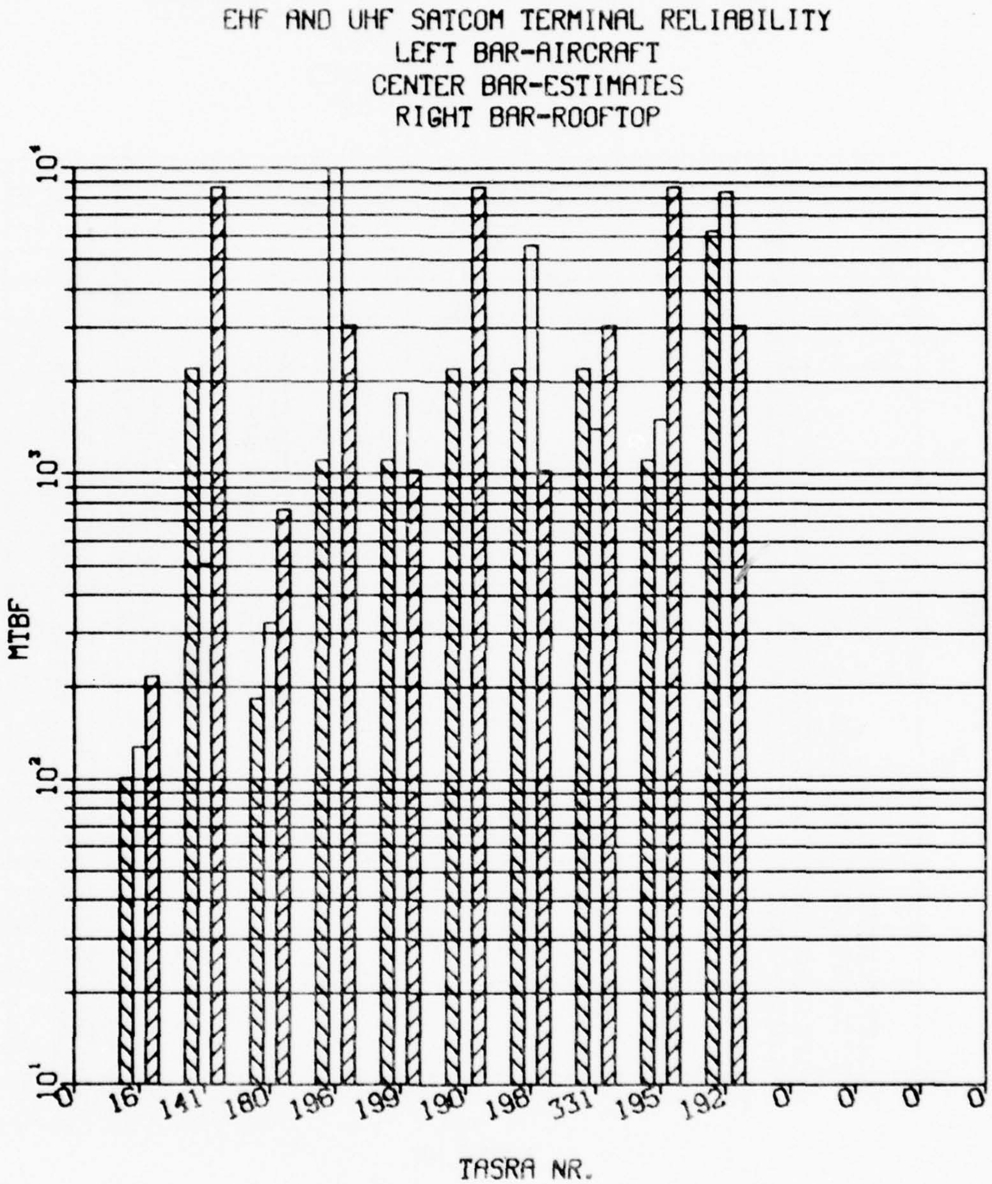



Figure 11

MODEM/Signal Processing

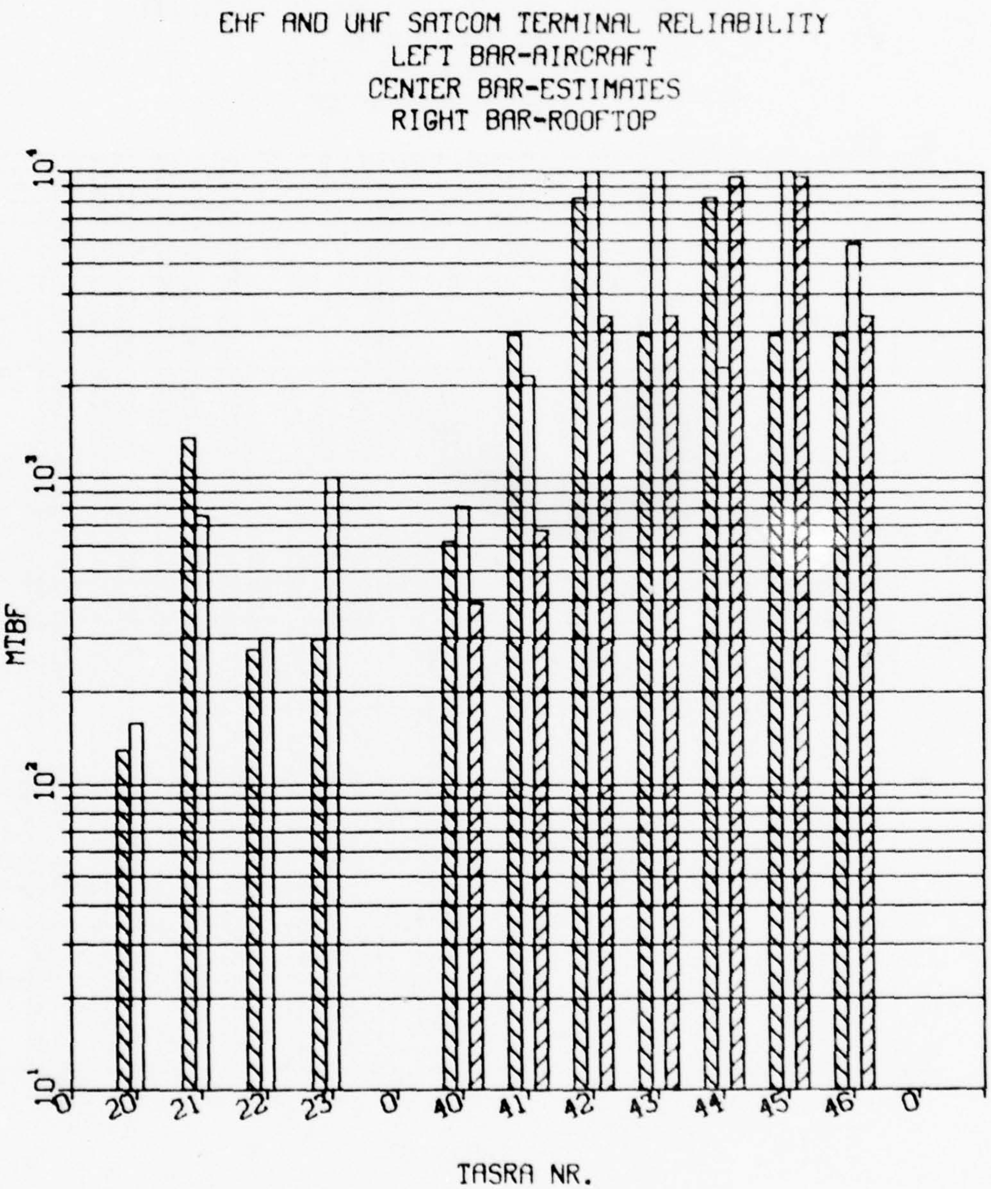



Figure 12

Communication Control and
Antenna Control Groups

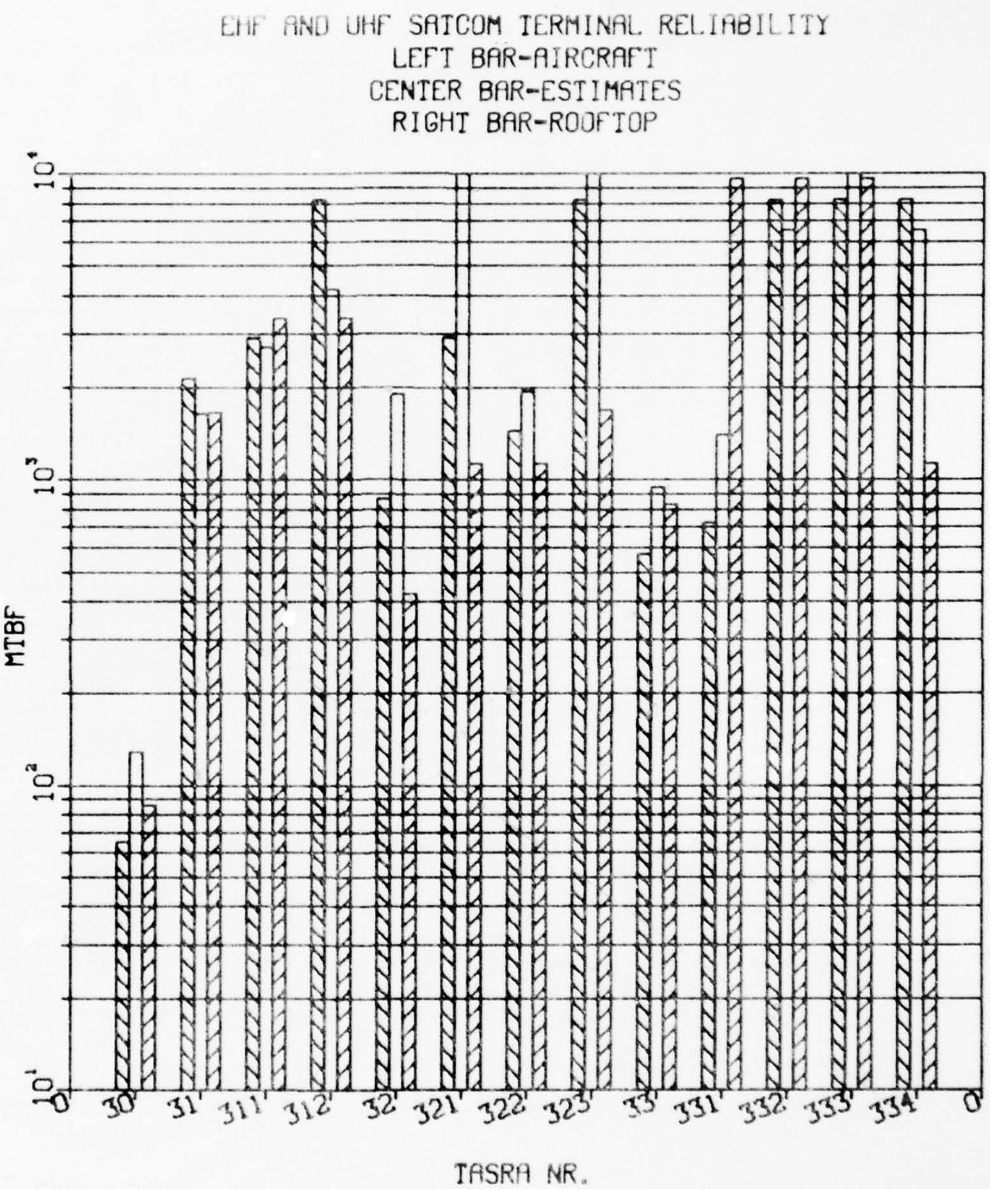



Figure 13

Communication Terminal Group - I

EHF AND UHF SATCOM TERMINAL RELIABILITY
LEFT BAR-AIRCRAFT
CENTER BAR-ESTIMATES
RIGHT BAR-ROOFTOP

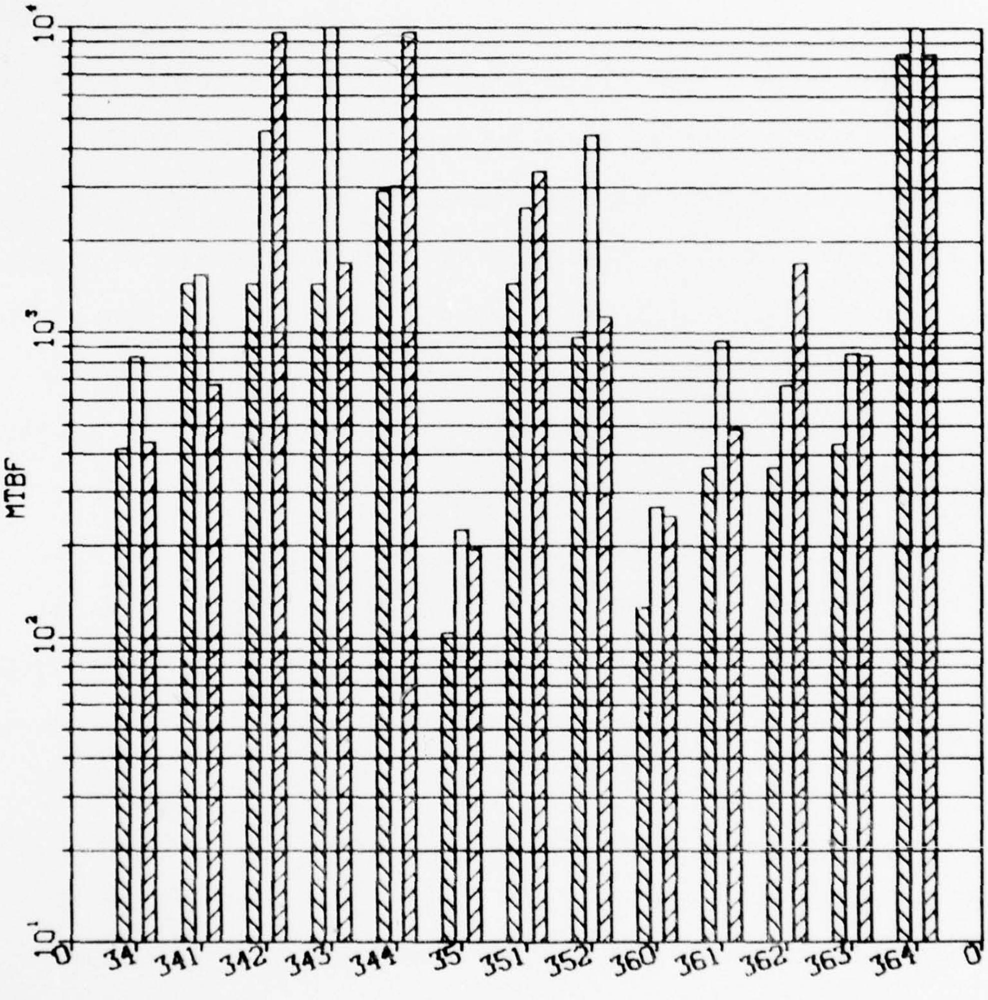



Figure 14

Communication Terminal Group - II

and Figure 9 no failures were recorded. Therefore, based on the total system operating hours at each location, the MTBF was computed at the 60% level. The predicted MTBF was assigned an initial 1000 hours, as shown in Table 1.

Modem/Processor Group - TASRA No. 10 Table 4, with Figures 10 and 11, shows that reliability of the signal processing subgroup-16 at the aircraft location was slightly less than that estimated, and at the rooftop location it was slightly more. The SYNCH/DEMUX units-180/181 experienced the greatest number of failures resulting in an overall MODEM/Processor Group-10 MTBF of 61 hours for the aircraft location. However, in the rooftop location these units-180/181 experienced a comparable number of failures to that of other subgroups. A major problem area with these units was the use of wire wrap modules which in the aircraft location had a tendency to experience shorted pin connections at the sub-unit integrated circuit elements.

Input/Output Group - TASRA No. 11 The input/output devices, which were generally off the shelf items, experienced malfunctions that did not always directly impact the system reliability, since various modes of operation were available. A nominal MTBF of 1000 hours was estimated for the input/output group, with the devices generally experiencing fewer failures on the aircraft than on the rooftop. Possibly, greater care was given to use of the devices on the aircraft.

Communication Control Group - TASRA No. 20 The Communication Control Group (OK-227), as shown in Table 5 and Figure 12, experienced the greatest number of failures in the Communication Control Computer-22. The total number of failures (13) for the Group-20 included failures attributed to associated units. The reliability experienced by Group-20 is comparable to that experienced on the SHF SATCOM Set Test Program of 1973 (2). In addition, the observed INS-21 unit MTBF of 1350 hours appears to be closer to the estimated 1333 hours in the SHF SATCOM Set test report (2) and is higher than the estimated MTBF of 750 hours.

Antenna Control Group - TASRA No. 40 The Antenna Control Group, Table 5 and Figure 12, shows that most failures occurred in subgroup-41, "Antenna Control Monitor". This may have been caused by design problems relating to the rooftop 10-ft. assembly in lieu of the aircraft 3-ft. antenna assembly which was flight qualified.

Communication Terminal Group - TASRA No. 30 As summarized in Table 6, with Figures 13 and 14, results of the rooftop installation MTBF were comparable to those experienced on the aircraft installation. The transmission subgroup-35 for the aircraft experienced 27 failures, and 17 failures were experienced at the rooftop installation. However, the low-noise amplifier on the rooftop installation experienced five failures to the two experienced on the aircraft installation. This shows generally, that the greater

stressed in the aircraft environment, when compared to the rooftop laboratory environment, resulted in a larger number of failures in the aircraft. The reliability data have to some degree been compromised by the fact that some of the elemental units have been interchanged during the test program.

OBSERVED MALFUNCTION TO RELEVANT FAILURE COMPARED

The monthly observed MTBF (malfunctions) and the cumulative observed MTBF (malfunctions), are given as part of Appendix A. Tables 9 through 16 and Figures 15 through 27 are summarized in Table 7. A comparison was made of the observed malfunction to failure data with the MTBF calculations based on relevant failures as shown in Table 7. Note that for the EHF system under test on the aircraft, two-thirds of the 150 malfunctions were determined to be relevant failures, while in the rooftop environment, 71 relevant failures to 89 observed malfunctions were recorded. This could suggest that the aircraft environment places a greater stress of the operational aspects of the equipment.

MODELS A AND B COMPARISON

Table 7 shows that adding redundancy to the Communication Control Group (20/20A) by increasing the MTBF from 158 hours (predicted) and 156 hours (observed) for Model A to 2423 hours and 1460 hours for Model B did not greatly influence the overall Ka-Band Set observed reliability. This was shown by the MTBF value of 23 hours for Model A and an MTBF value of 29 hours for Model B.

TABLE 7 SYSTEM MTBF SUMMARY FOR MODELS "A" AND "B"

| TASRA Nr. | PREDICTED MTBF | AIRCRAFT DATA MALFUNCTIONS | FAILURES | MTBF+ | ROOFTOP DATA MALFUNCTIONS | FAILURES | MTBF+ |
|---|---|---|---|---|---|---|---|
| 1 | 35 | 217 | 135 | 18 | 105 | 82 | 34 |
| 2 | 39 | 150 | 100 | 23 | 89 | 71 | 42 |
| 10 | 364 | 46 | 36 | 61 | 23 | 17 | 147 |
| 11 | 1000 | 11 | 3 | 595 | 17 | 9 | 327 |
| 20 | 158 | 34 | 13 | 156 | --- | --- | ---- |
| 30 | 129 | 52 | 44 | 65 | 37 | 37 | 86 |
| 40 | 808 | 7 | 4 | 616 | 9 | 8 | 389 |
| 3 | 517 | 67 | 35 | 90 | 16 | 13 | 193 |
| U-I/O | 2000 | 7 | 5 | 616 | 2 | 2 | 1251 |
| 50 | 1278 | 8 | 3 | 434 | 10 | 8 | 313 |
| 60 | 1476 | 19 | 8 | 163 | 3 | 3 | 834 |
| 70 | 1300 | 14 | 9 | 198 | --- | --- | ---- |
| 80 | 1500 | 19 | 10 | 178 | --- | --- | ---- |
| | MODEL "B" | | | | | | |
| 2 | 52 | | | 29 | | | |
| 20/20A | 2423 | | | 1460 | | | |
| 30A | 135 | | | 69 | | | |
| 40A | 868 | | | 976 | | | |

+ FINAL CUMULATIVE MTBF BASED ON RELEVANT FAILURES ONLY

## SUMMARY

The cumulative reliability data for the EHF and UHF SATCOM Set are shown in Figures 9 through 14 for Model A. The bar graphs allow a rapid comparison of MTBF observed for the aircraft and rooftop data to that of the MTBF predicted down to the elemental level.

The data in Table 7 were tabulated to provide the final cumulative MTBF, counting relevant failures only, for each of the SATCOM Sets and Groups. In addition, the number of accumulated malfunctions, as given in Appendix A, is compared to the relevant failures. Also, this table allows for a rapid assessment of reliability achieved during the test program versus that predicted for Models A and B.

Model A reliability data for the EHF SATCOM Set were calculated for both the aircraft and rooftop locations based on observed relevant failures. For the aircraft location, the reliability in terms of MTBF was 23 hours and 29 hours respectively, for a fully operating and minimum modeled system. This was compared to the predicted EHF SATCOM Set of 39 hours and 52 hours for the two models. (Tables 7 and 8).

Adding redundancy to Communication Control Group-20 did not significantly increase the reliability of the system. To achieve any significant increase in system reliability, more attention should be given to improving the Communication Terminal Group-30 and the MODEM/Processor Group-10.

TABLE 8 PREDICTED AND FINAL OBSERVED RELIABILITY FOR THE Ka-BAND SYSTEM SUBGROUP AND GROUP ELEMENTS

| TITLE | PREDICTED MTBF@ | AIRCRAFT MTBF+ | ROOFTOP MTBF+ |
|---|---|---|---|
| MODEM-PROCESSOR GROUP | 107 | 61 | 147 |
| ANTENNA ALIGNMENT | 11981 | 2208 | 8645# |
| POWER CONTROL PANEL | 15664 | 1104 | 8645# |
| ROLM 1602 COMPUTER | 981 | 441 | 764 |
| MODEM CONTROL PANEL | 3054 | 368 | 1528 |
| MESSAGE PROCESSING UNITS | 506 | 2207 | 8645# |
| SYNCH-DEMUX UNITS | 324 | 184 | 764 |
| CODE GENERATOR | 1993 | 2207 | 8645# |
| FREQ SYNTH | 1500 | 1104 | 8645# |
| RUBIDIUM STANDARD | 1405 | 2207 | 3056 |
| REPORT BACK DEMOD | 1830 | 1104 | 1019 |
| FOREWARD-REPORT BACK | 17497 | 1104 | 3056 |
| CONFERENCE DECODE | 5582 | 2207 | 1019 |
| MODULATOR | 8374 | 6244# | 3056 |
| INPUT-OUTPUT GROUP | 1000 | 595 | 327 |
| COMMUNICATION CONTROL GROUP | | | |
| MODEL "A" | 158 | 156 | ---- |
| MODEL "B" | 2423 | 1460 | ---- |
| ANTENNA CONTROL GROUP | | | |
| MODEL "A" | 808 | 616 | 389 |
| MODEL "B" | 868 | 976 | ---- |
| SATCOM SET (Ka-BAND) | | | |
| MODEL "A" | 39 | 23 | 42 |
| MODEL "B" | 52 | 29 | ---- |

+ FINAL CUMULATIVE MTBF BASED ON RELEVANT FAILURES

# CALCULATED AT 60% CONFIDENCE LEVEL

@ COMBINED MTBF ESTIMATES PER BCL

TABLE 8 PREDICTED AND FINAL OBSERVED RELIABILITY FOR THE Ka-BAND SYSTEM SUBGROUP AND GROUP ELEMENTS (Continued)

| TITLE | PREDICTED MTBF@ | AIRCRAFT MTBF+ | ROOFTOP MTBF+ |
|---|---|---|---|
| COMMUNICATION TERMINAL GROUP | | | |
| MODEL "A" | 129 | 65 | 86 |
| MODEL "B" | 135 | 69 | ---- |
| POWER DISTRIBUTION | 2713 | 2901 | 3385 |
| LOW VOLTAGE POWER SUPPLY | 4196 | 8207# | 3385 |
| LIQUID-AIR HEAT EXCHANGER | 100000 | 2901 | 1128 |
| PUMP-CONTROL MODULE | 1939 | 1451 | 1128 |
| COOLANT LINE-FITTINGS | 100000 | 8207# | 1693 |
| RUBIDIUM STANDARD | 1405 | 725 | 9576# |
| 1 MHz FREQ SYNTH | 6537 | 8207# | 9576# |
| STEPPABLE FREQ SYNTH | 24732 | 8207# | 9576# |
| FREQ GENERATOR | 6524 | 8207# | 1128 |
| LOW NOISE AMPLIFIER | 1548 | 1451 | 677 |
| DOWN CONVERTOR | 4570 | 1451 | 9576# |
| RECEIVER | 100000 | 1451 | 1693 |
| AUTO TRACK RECEIVER | 3028 | 2901 | 9576# |
| DOPPLER CORRECTOR | 2555 | 1451 | 3385 |
| EXCITER | 4436 | 967 | 1128 |
| RF MODULE (TWT) | 949 | 363 | 484 |
| HIGH VOLTAGE POWER SUPPLY | 675 | 363 | 1693 |
| TRANSMITTER LOCAL CONTROL | 855 | 434 | 846 |
| TRANSMITTER REMOTE CONTROL | 27065 | 8207# | 9576# |

A major thrust of this program was to assess the EHF SATCOM Set reliability. The data collected for the UHF SATCOM Set were supplemental to the extent of assessing the reliability for the MODEM and transceiver level only for both the aircraft and rooftop locations.

During the test program, a number of potential design problems were identified by the large number of failures experienced at specific elemental levels. Primarily, these problems appeared in the EHF Communication Terminal Group-30 and the MODEM/Processor Group-10 as shown in Summary Tables 7 and 8.

# CHAPTER 6

## CONCLUSIONS AND RECOMMENDATIONS

The results of the assessment conducted in this study obviously indicated that the EHF SATCOM Set, which is highly complex, can be expected to have a relatively high incidence of malfunction. It appears, however, that potential reliability growth to an MTBF of approximately 60 hours may be obtained. This is based on findings from the analysis of the data obtained from flight test malfunction reports discussed in Chapter five. Growth beyond this level will require considerable reliability improvement for the two groups, the EHF communication terminal and the MODEM, which are currently experiencing most of the failures.

To reach an MTBF of 100 hours or more, extensive redesign of the RF terminal would probably be required to avoid using redundancy extensively as a main reliability improvement approach, an approach which can be costly from a weight and volume point of view.

Recommendations for further consideration include a reliability improvement program which addresses the use of printed circuits in place of wire wrap in the MODEM/Processor Group and the redesign of the high power amplifier and power supply in the Communication Terminal Group.

As discussed in the review of relevant literature, Chapter 2, reliability is most easily obtained when it is built into the equipment, not added on later by a modification after too many failures. Reliability requirements should be compatible with costs, schedules, and performance, and should be based upon an operational analysis of the system to insure that the system is optimized with respect to its proposed mission. There are several ways of increasing the reliability of the equipment:

1. a definite level of reliability may be bought in the original contract for the equipment, including a testing program;
2. the equipment may be modified to increase the reliability;
3. redundant circuits and/or components may be used to increased reliability; and
4. derating of parts may be used for greater reliability.

Of these methods, the preferred method is to buy a reliable design and the necessary testing to prove the reliability of the design in the original contract. Thus, costly actions to provide reliability are prevented after the equipment is in the field.

APPENDIXES

## APPENDIX A

## TABULATED AND PLOTTED OBSERVED MONTHLY AND CUMULATIVE RELIABILITY DATA

The tabulations in Tables 9 through 16 and the plotted data in Figures 15 through 27 are presented here to provide backup data for Tables 3 through 8 and to cover the observed malfunction failure and the operating hours presented in the body of this technical report.

The malfunction data observed either on the aircraft or rooftop were presented in Model A only. The malfunction event analysis sheets were obtained for each group and were reduced to the tabulated data of Tables 9 through 16. These groups for the aircraft and rooftop locations are listed below. The malfunction event analysis sheets were re-evaluated and hard core failures were identified and tabulated in Tables 3 through 8 (7).

| TASRA NUMBER | GROUP NAME |
|---|---|
| 10 | Modem/Processor |
| 11 | Input/Output Equipment |
| 20 | Communication Control |
| 30 | Communication Terminal |
| 40 | Antenna Control |
| 50 | ARC-171 Transceiver |
| 60 | UHF Modem |
| 70 | ARC-171 Transceiver |
| 80 | Dual Modem |

TABLE 9

| MONTH | OP. HOURS | CUMULATIVE OP. HOURS | MALFUNCTIONS MONTH | MALFUNCTIONS CUM. | OBSERVED MTBF MONTH | OBSERVED MTBF CUM. |
|---|---|---|---|---|---|---|
| **662 AIRCRAFT** | | | | | | |
| **KA-BAND SYSTEM** | | | | | | |
| **SSMP GROUP (EXCLUDING UHF) ---(10)---** | | | | | | |
| 1976 | | | | | | |
| OCT | 791. | 791. | 25 | 25 | 31.6 | 31.6 |
| NOV | 361. | 1152. | 5 | 30 | 72.2 | 38.4 |
| DEC | 474. | 1626. | 3 | 33 | 158.0 | 49.3 |
| 1977 | | | | | | |
| JAN | 71. | 1697. | 2 | 35 | 35.5 | 48.5 |
| FEB | 24. | 1721. | 1 | 36 | 24.0 | 47.8 |
| MAR | 125. | 1846. | 1 | 37 | 125.0 | 49.9 |
| APR | 0. | 1846. | 0 | 37 | ********* | 49.9 |
| MAY | 35. | 1881. | 2 | 39 | 17.5 | 48.2 |
| JUN | 83. | 1964. | 2 | 41 | 41.5 | 47.9 |
| JUL | 74. | 2038. | 3 | 44 | 24.7 | 46.3 |
| AUG | 100. | 2138. | 2 | 46 | 50.0 | 46.5 |
| SEP | 69. | 2207. | 0 | 46 | ********* | 48.0 |
| **KA-BAND TERMINAL GROUP ---(30)---** | | | | | | |
| 1976 | | | | | | |
| OCT | 1297. | 1297. | 19 | 19 | 68.3 | 68.3 |
| NOV | 398. | 1695. | 2 | 21 | 199.0 | 80.7 |
| DEC | 502. | 2197. | 4 | 25 | 125.5 | 87.9 |
| 1977 | | | | | | |
| JAN | 85. | 2282. | 4 | 29 | 21.3 | 78.7 |
| FEB | 63. | 2345. | 3 | 32 | 21.0 | 73.3 |
| MAR | 125. | 2470. | 3 | 35 | 41.7 | 70.6 |
| APR | 0. | 2470. | 0 | 35 | ********* | 70.6 |
| MAY | 63. | 2533. | 1 | 36 | 63.0 | 70.4 |
| JUN | 89. | 2622. | 0 | 36 | ********* | 72.8 |
| JUL | 83. | 2705. | 3 | 39 | 27.7 | 69.4 |
| AUG | 119. | 2824. | 5 | 44 | 23.8 | 64.2 |
| SEP | 77. | 2901. | 8 | 52 | 9.6 | 55.8 |
| **ANTENNA CONTROL GROUP ---(40)---** | | | | | | |
| 1976 | | | | | | |
| OCT | 1297. | 1297. | 5 | 5 | 259.4 | 259.4 |
| NOV | 398. | 1695. | 0 | 5 | ********* | 339.0 |
| DEC | 502. | 2197. | 0 | 5 | ********* | 439.4 |
| 1977 | | | | | | |
| JAN | 85. | 2282. | 0 | 5 | ********* | 456.4 |
| FEB | 63. | 2345. | 1 | 6 | 63.0 | 390.8 |
| MAR | 125. | 2470. | 1 | 7 | 125.0 | 352.9 |
| APR | 0. | 2470. | 0 | 7 | ********* | 352.9 |
| MAY | 63. | 2533. | 0 | 7 | ********* | 361.9 |
| JUN | 89. | 2622. | 0 | 7 | ********* | 374.6 |
| JUL | 83. | 2705. | 0 | 7 | ********* | 386.4 |
| AUG | 119. | 2824. | 0 | 7 | ********* | 403.4 |
| SEP | 77. | 2901. | 0 | 7 | ********* | 414.4 |

TABLE 10

| MONTH | OP. HOURS | CUMULATIVE OP. HOURS | MALFUNCTIONS MONTH | MALFUNCTIONS CUM. | OBSERVED MTBF MONTH | OBSERVED MTBF CUM. |
|---|---|---|---|---|---|---|
| 662 AIRCRAFT | | | | | | |
| KA-BAND SYSTEM | | | | | | |
| COMMUNICATIONS CONTROL GROUP ---(20)--- | | | | | | |
| 1976 | | | | | | |
| OCT | 698. | 698. | 25 | 25 | 27.9 | 27.9 |
| NOV | 80. | 778. | 2 | 27 | 40.0 | 28.8 |
| DEC | 87. | 865. | 0 | 27 | ********* | 32.0 |
| 1977 | | | | | | |
| JAN | 90. | 955. | 1 | 28 | 90.0 | 34.1 |
| FEB | 23. | 978. | 1 | 29 | 23.0 | 33.7 |
| MAR | 135. | 1113. | 1 | 30 | 135.0 | 37.1 |
| APR | 0. | 1113. | 0 | 30 | ********* | 37.1 |
| MAY | 63. | 1176. | 1 | 31 | 63.0 | 37.9 |
| JUN | 96. | 1272. | 1 | 32 | 96.0 | 39.8 |
| JUL | 63. | 1335. | 2 | 34 | 31.5 | 39.3 |
| AUG | 99. | 1434. | 0 | 34 | ********* | 42.2 |
| SEP | 63. | 1497. | 0 | 34 | ********* | 44.0 |
| INS ---(21)--- | | | | | | |
| 1976 | | | | | | |
| OCT | 577. | 577. | 4 | 4 | 144.3 | 144.3 |
| NOV | 55. | 632. | 0 | 4 | ********* | 158.0 |
| DEC | 87. | 719. | 0 | 4 | ********* | 179.8 |
| 1977 | | | | | | |
| JAN | 89. | 808. | 0 | 4 | ********* | 202.0 |
| FEB | 23. | 831. | 0 | 4 | ********* | 207.8 |
| MAR | 135. | 966. | 0 | 4 | ********* | 241.5 |
| APR | 0. | 966. | 0 | 4 | ********* | 241.5 |
| MAY | 63. | 1029. | 0 | 4 | ********* | 257.3 |
| JUN | 96. | 1125. | 0 | 4 | ********* | 281.3 |
| JUL | 63. | 1188. | 1 | 5 | 63.0 | 237.6 |
| AUG | 99. | 1287. | 0 | 5 | ********* | 257.4 |
| SEP | 63. | 1350. | 0 | 5 | ********* | 270.0 |
| COMMUNICATIONS CONTRL COMPUTER ---(22)--- | | | | | | |
| 1976 | | | | | | |
| OCT | 698. | 698. | 21 | 21 | 33.2 | 33.2 |
| NOV | 80. | 778. | 2 | 23 | 40.0 | 33.8 |
| DEC | 87. | 865. | 0 | 23 | ********* | 37.6 |
| 1977 | | | | | | |
| JAN | 90. | 955. | 1 | 24 | 90.0 | 39.8 |
| FEB | 20. | 975. | 1 | 25 | 20.0 | 39.0 |
| MAR | 119. | 1094. | 1 | 26 | 119.0 | 42.1 |
| APR | 0. | 1094. | 0 | 26 | ********* | 42.1 |
| MAY | 52. | 1146. | 1 | 27 | 52.0 | 42.4 |
| JUN | 85. | 1231. | 1 | 28 | 85.0 | 44.0 |
| JUL | 46. | 1277. | 1 | 29 | 46.0 | 44.0 |
| AUG | 47. | 1324. | 0 | 29 | ********* | 45.7 |
| SEP | 52. | 1376. | 0 | 29 | ********* | 47.4 |

TABLE 11

| MONTH | OP. HOURS | CUMULATIVE OP. HOURS | MALFUNCTIONS MONTH | MALFUNCTIONS CUM. | OBSERVED MTBF MONTH | OBSERVED MTBF CUM. |
|---|---|---|---|---|---|---|
| 662 AIRCRAFT | | | | | | |
| UHF SYSTEM | | | | | | |
| FORCE ELEMENT GROUP | | | | | | |
| ARC-151 RECEIVER/TRANSMITTER ---(50)--- | | | | | | |
| 1976 | | | | | | |
| OCT | 632. | 632. | 5 | 5 | 126.4 | 126.4 |
| NOV | 74. | 706. | 0 | 5 | ********* | 141.2 |
| DEC | 70. | 776. | 0 | 5 | ********* | 155.2 |
| 1977 | | | | | | |
| JAN | 36. | 812. | 1 | 6 | 36.0 | 135.3 |
| FEB | 105. | 917. | 1 | 7 | 105.0 | 131.0 |
| MAR | 100. | 1017. | 0 | 7 | ********* | 145.3 |
| APR | 0. | 1017. | 0 | 7 | ********* | 145.3 |
| MAY | 15. | 1032. | 0 | 7 | ********* | 147.4 |
| JUN | 51. | 1083. | 1 | 8 | 51.0 | 135.4 |
| JUL | 31. | 1114. | 0 | 8 | ********* | 139.3 |
| AUG | 119. | 1233. | 0 | 8 | ********* | 154.1 |
| SEP | 68. | 1301. | 0 | 8 | ********* | 162.6 |
| UHF MODEM ---(60)--- | | | | | | |
| 1976 | | | | | | |
| OCT | 632. | 632. | 6 | 6 | 105.3 | 105.3 |
| NOV | 74. | 706. | 2 | 8 | 37.0 | 88.3 |
| DEC | 70. | 776. | 1 | 9 | 70.0 | 86.2 |
| 1977 | | | | | | |
| JAN | 36. | 812. | 2 | 11 | 18.0 | 73.8 |
| FEB | 105. | 917. | 2 | 13 | 52.5 | 70.5 |
| MAR | 100. | 1017. | 1 | 14 | 100.0 | 72.6 |
| APR | 0. | 1017. | 0 | 14 | ********* | 72.6 |
| MAY | 15. | 1032. | 0 | 14 | ********* | 73.7 |
| JUN | 51. | 1083. | 1 | 15 | 51.0 | 72.2 |
| JUL | 31. | 1114. | 0 | 15 | ********* | 74.3 |
| AUG | 119. | 1233. | 3 | 18 | 39.7 | 68.5 |
| SEP | 68. | 1301. | 1 | 19 | 68.0 | 68.5 |

TABLE 12

| MONTH | OP. HOURS | CUMULATIVE OP. HOURS | MALFUNCTIONS MONTH | MALFUNCTIONS CUM. | OBSERVED MTBF MONTH | OBSERVED MTBF CUM. |
|---|---|---|---|---|---|---|
| **662 AIRCRAFT** | | | | | | |
| **UHF SYSTEM** | | | | | | |
| **DUAL UHF GROUP** | | | | | | |
| **ARC-171 RECEIVER/TRANSMITTER ---(70)---** | | | | | | |
| 1976 | | | | | | |
| OCT | 808. | 808. | 8 | 8 | 101.0 | 101.0 |
| NOV | 77. | 885. | 1 | 9 | 77.0 | 98.3 |
| DEC | 63. | 948. | 2 | 11 | 31.5 | 86.2 |
| 1977 | | | | | | |
| JAN | 118. | 1066. | 0 | 11 | ********* | 96.9 |
| FEB | 96. | 1162. | 0 | 11 | ********* | 105.6 |
| MAR | 145. | 1307. | 0 | 11 | ********* | 118.8 |
| APR | 79. | 1386. | 2 | 13 | 39.5 | 106.6 |
| MAY | 71. | 1457. | 0 | 13 | ********* | 112.1 |
| JUN | 72. | 1529. | 0 | 13 | ********* | 117.6 |
| JUL | 54. | 1583. | 1 | 14 | 54.0 | 113.1 |
| AUG | 132. | 1715. | 0 | 14 | ********* | 122.5 |
| SEP | 66. | 1781. | 0 | 14 | ********* | 127.2 |
| **DUAL MODEM ---(80)---** | | | | | | |
| 1976 | | | | | | |
| OCT | 808. | 808. | 14 | 14 | 57.7 | 57.7 |
| NOV | 77. | 885. | 0 | 14 | ********* | 63.2 |
| DEC | 63. | 948. | 0 | 14 | ********* | 67.7 |
| 1977 | | | | | | |
| JAN | 118. | 1066. | 1 | 15 | 118.0 | 71.1 |
| FEB | 96. | 1162. | 0 | 15 | ********* | 77.5 |
| MAR | 145. | 1307. | 0 | 15 | ********* | 87.1 |
| APR | 79. | 1386. | 1 | 16 | 79.0 | 86.6 |
| MAY | 71. | 1457. | 0 | 16 | ********* | 91.1 |
| JUN | 72. | 1529. | 0 | 16 | ********* | 95.6 |
| JUL | 54. | 1583. | 0 | 16 | ********* | 98.9 |
| AUG | 132. | 1715. | 0 | 16 | ********* | 107.2 |
| SEP | 66. | 1781. | 3 | 19 | 22.0 | 93.7 |

TABLE 13

| MONTH | OP. HOURS | CUMULATIVE OP. HOURS | MALFUNCTIONS MONTH | MALFUNCTIONS CUM. | OBSERVED MTBF MONTH | OBSERVED MTBF CUM. |
|---|---|---|---|---|---|---|
| 662 AIRCRAFT | | | | | | |
| KA-BAND SYSTEM | | | | | | |
| INPUT/OUTPUT GROUP ---(11)--- | | | | | | |
| 1976 | | | | | | |
| OCT | 791. | 791. | 6 | 6 | 131.8 | 131.8 |
| NOV | 361. | 1152. | 0 | 6 | ********* | 192.0 |
| DEC | 474. | 1626. | 0 | 6 | ********* | 271.0 |
| 1977 | | | | | | |
| JAN | 71. | 1697. | 1 | 7 | 71.0 | 242.4 |
| FEB | 24. | 1721. | 2 | 9 | 12.0 | 191.2 |
| MAR | 125. | 1846. | 0 | 9 | ********* | 205.1 |
| APR | 0. | 1846. | 0 | 9 | ********* | 205.1 |
| MAY | 35. | 1881. | 2 | 11 | 17.5 | 171.0 |
| JUN | 83. | 1964. | 0 | 11 | ********* | 178.5 |
| JUL | 74. | 2038. | 0 | 11 | ********* | 185.3 |
| AUG | 100. | 2138. | 0 | 11 | ********* | 194.4 |
| SEP | 69. | 2207. | 0 | 11 | ********* | 200.6 |
| UHF SYSTEM | | | | | | |
| INPUT/OUTPUT GROUP ---(U-I/O)--- | | | | | | |
| 1976 | | | | | | |
| OCT | 1440. | 1440. | 4 | 4 | 360.0 | 360.0 |
| NOV | 151. | 1591. | 0 | 4 | ********* | 397.8 |
| DEC | 133. | 1724. | 0 | 4 | ********* | 431.0 |
| 1977 | | | | | | |
| JAN | 154. | 1878. | 0 | 4 | ********* | 469.5 |
| FEB | 201. | 2079. | 1 | 5 | 201.0 | 415.8 |
| MAR | 245. | 2324. | 0 | 5 | ********* | 464.8 |
| APR | 79. | 2403. | 0 | 5 | ********* | 480.6 |
| MAY | 86. | 2489. | 1 | 6 | 86.0 | 414.8 |
| JUN | 123. | 2612. | 0 | 6 | ********* | 435.3 |
| JUL | 85. | 2697. | 1 | 7 | 85.0 | 385.3 |
| AUG | 251. | 2948. | 0 | 7 | ********* | 421.1 |
| SEP | 134. | 3082. | 0 | 7 | ********* | 440.3 |

TABLE 14

| MONTH | OP. HOURS | CUMULATIVE OP. HOURS | MALFUNCTIONS MONTH | MALFUNCTIONS CUM. | OBSERVED MTBF MONTH | OBSERVED MTBF CUM. |
|---|---|---|---|---|---|---|
| ROOFTOP LABORATORY | | | | | | |
| KA-BAND SYSTEM | | | | | | |
| SSMP GROUP (EXCLUDING UHF) ---(10)--- | | | | | | |
| 1976 | | | | | | |
| OCT | 1473. | 1473. | 11 | 11 | 133.9 | 133.9 |
| NOV | 127. | 1600. | 1 | 12 | 127.0 | 133.3 |
| DEC | 93. | 1693. | 0 | 12 | ********* | 141.1 |
| 1977 | | | | | | |
| JAN | 140. | 1833. | 1 | 13 | 140.0 | 141.0 |
| FEB | 154. | 1987. | 2 | 15 | 77.0 | 132.5 |
| MAR | 253. | 2240. | 2 | 17 | 126.5 | 131.8 |
| APR | 174. | 2414. | 0 | 17 | ********* | 142.0 |
| MAY | 128. | 2542. | 0 | 17 | ********* | 149.5 |
| JUN | 143. | 2685. | 0 | 17 | ********* | 157.9 |
| JUL | 152. | 2837. | 3 | 20 | 50.7 | 141.9 |
| AUG | 171. | 3008. | 1 | 21 | 171.0 | 143.2 |
| SEP | 48. | 3056. | 2 | 23 | 24.0 | 132.9 |
| KA-BAND TERMINAL GROUP ---(30)--- | | | | | | |
| 1976 | | | | | | |
| OCT | 1375. | 1375. | 16 | 16 | 85.9 | 85.9 |
| NOV | 126. | 1501. | 2 | 18 | 63.0 | 83.4 |
| DEC | 334. | 1835. | 2 | 20 | 167.0 | 91.8 |
| 1977 | | | | | | |
| JAN | 77. | 1912. | 3 | 23 | 25.7 | 83.1 |
| FEB | 214. | 2126. | 0 | 23 | ********* | 92.4 |
| MAR | 264. | 2390. | 1 | 24 | 264.0 | 99.6 |
| APR | 134. | 2524. | 4 | 28 | 33.5 | 90.1 |
| MAY | 139. | 2663. | 3 | 31 | 46.3 | 85.9 |
| JUN | 142. | 2805. | 2 | 33 | 71.0 | 85.0 |
| JUL | 365. | 3170. | 2 | 35 | 182.5 | 90.6 |
| AUG | 136. | 3306. | 1 | 36 | 136.0 | 91.8 |
| SEP | 79. | 3385. | 1 | 37 | 79.0 | 91.5 |
| ANTENNA CONTROL GROUP ---(40)--- | | | | | | |
| 1976 | | | | | | |
| OCT | 1375. | 1375. | 6 | 6 | 229.2 | 229.2 |
| NOV | 126. | 1501. | 0 | 6 | ********* | 250.2 |
| DEC | 334. | 1835. | 0 | 6 | ********* | 305.9 |
| 1977 | | | | | | |
| JAN | 77. | 1912. | 0 | 6 | ********* | 318.7 |
| FEB | 214. | 2126. | 2 | 8 | 107.0 | 265.8 |
| MAR | 264. | 2390. | 0 | 8 | ********* | 298.8 |
| APR | 134. | 2524. | 1 | 9 | 134.0 | 280.4 |
| MAY | 139. | 2663. | 0 | 9 | ********* | 295.9 |
| JUN | 142. | 2805. | 0 | 9 | ********* | 311.7 |
| JUL | 365. | 3170. | 0 | 9 | ********* | 352.2 |
| AUG | 136. | 3306. | 0 | 9 | ********* | 367.3 |
| SEP | 79. | 3385. | 0 | 9 | ********* | 376.1 |

TABLE 15

| MONTH | OP. HOURS | CUMULATIVE OP. HOURS | MALFUNCTIONS MONTH | MALFUNCTIONS CUM. | OBSERVED MTBF MONTH | OBSERVED MTBF CUM. |
|---|---|---|---|---|---|---|
| ROOFTOP LABORATORY | | | | | | |
| UHF SYSTEM | | | | | | |
| FORCE ELEMENT GROUP | | | | | | |
| ARC-151 RECEIVER/TRANSMITTER ---(50)--- | | | | | | |
| 1976 | | | | | | |
| OCT | 1480. | 1480. | 8 | 8 | 185.0 | 185.0 |
| NOV | 110. | 1590. | 1 | 9 | 110.0 | 176.7 |
| DEC | 70. | 1660. | 0 | 9 | ********* | 184.4 |
| 1977 | | | | | | |
| JAN | 90. | 1750. | 0 | 9 | ********* | 194.4 |
| FEB | 36. | 1786. | 0 | 9 | ********* | 198.4 |
| MAR | 39. | 1825. | 0 | 9 | ********* | 202.8 |
| APR | 140. | 1965. | 0 | 9 | ********* | 218.3 |
| MAY | 169. | 2134. | 0 | 9 | ********* | 237.1 |
| JUN | 92. | 2226. | 1 | 10 | 92.0 | 222.6 |
| JUL | 30. | 2256. | 0 | 10 | ********* | 225.6 |
| AUG | 120. | 2376. | 0 | 10 | ********* | 237.6 |
| SEP | 125. | 2501. | 0 | 10 | ********* | 250.1 |
| UHF MODEM ---(60)--- | | | | | | |
| 1976 | | | | | | |
| OCT | 1480. | 1480. | 0 | 0 | ********* | ********* |
| NOV | 110. | 1590. | 0 | 0 | ********* | ********* |
| DEC | 70. | 1660. | 0 | 0 | ********* | ********* |
| 1977 | | | | | | |
| JAN | 90. | 1750. | 2 | 2 | 45.0 | 875.0 |
| FEB | 36. | 1786. | 0 | 2 | ********* | 893.0 |
| MAR | 39. | 1825. | 0 | 2 | ********* | 912.5 |
| APR | 140. | 1965. | 0 | 2 | ********* | 982.5 |
| MAY | 169. | 2134. | 0 | 2 | ********* | 1067.0 |
| JUN | 92. | 2226. | 1 | 3 | 92.0 | 742.0 |
| JUL | 30. | 2256. | 0 | 3 | ********* | 752.0 |
| AUG | 120. | 2376. | 0 | 3 | ********* | 792.0 |
| SEP | 125. | 2501. | 0 | 3 | ********* | 833.7 |

TABLE 16

| MONTH | OP. HOURS | CUMULATIVE OP. HOURS | MALFUNCTIONS MONTH | MALFUNCTIONS CUM. | OBSERVED MTBF MONTH | OBSERVED MTBF CUM. |
|---|---|---|---|---|---|---|
| ROOFTOP LABORATORY | | | | | | |
| KA-BAND SYSTEM | | | | | | |
| INPUT/OUTPUT GROUP ---(11)--- | | | | | | |
| 1976 | | | | | | |
| OCT | 1473. | 1473. | 7 | 7 | 210.4 | 210.4 |
| NOV | 127. | 1600. | 1 | 8 | 127.0 | 200.0 |
| DEC | 93. | 1693. | 2 | 10 | 46.5 | 169.3 |
| 1977 | | | | | | |
| JAN | 140. | 1833. | 1 | 11 | 140.0 | 166.6 |
| FEB | 154. | 1987. | 0 | 11 | ********* | 180.6 |
| MAR | 253. | 2240. | 1 | 12 | 253.0 | 186.7 |
| APR | 174. | 2414. | 0 | 12 | ********* | 201.2 |
| MAY | 128. | 2542. | 0 | 12 | ********* | 211.8 |
| JUN | 143. | 2685. | 0 | 12 | ********* | 223.8 |
| JUL | 152. | 2837. | 1 | 13 | 152.0 | 218.2 |
| AUG | 171. | 3008. | 2 | 15 | 85.5 | 200.5 |
| SEP | 48. | 3056. | 2 | 17 | 24.0 | 179.8 |
| UHF SYSTEM | | | | | | |
| INPUT/OUTPUT GROUP ---(U-I/O)--- | | | | | | |
| 1976 | | | | | | |
| OCT | 1480. | 1480. | 0 | 0 | ********* | ********* |
| NOV | 110. | 1590. | 0 | 0 | ********* | ********* |
| DEC | 70. | 1660. | 0 | 0 | ********* | ********* |
| 1977 | | | | | | |
| JAN | 90. | 1750. | 2 | 2 | 45.0 | 875.0 |
| FEB | 36. | 1786. | 0 | 2 | ********* | 893.0 |
| MAR | 39. | 1825. | 0 | 2 | ********* | 912.5 |
| APR | 140. | 1965. | 0 | 2 | ********* | 982.5 |
| MAY | 169. | 2134. | 0 | 2 | ********* | 1067.0 |
| JUN | 92. | 2226. | 0 | 2 | ********* | 1113.0 |
| JUL | 30. | 2256. | 0 | 2 | ********* | 1128.0 |
| AUG | 120. | 2376. | 0 | 2 | ********* | 1188.0 |
| SEP | 125. | 2501. | 0 | 2 | ********* | 1250.5 |

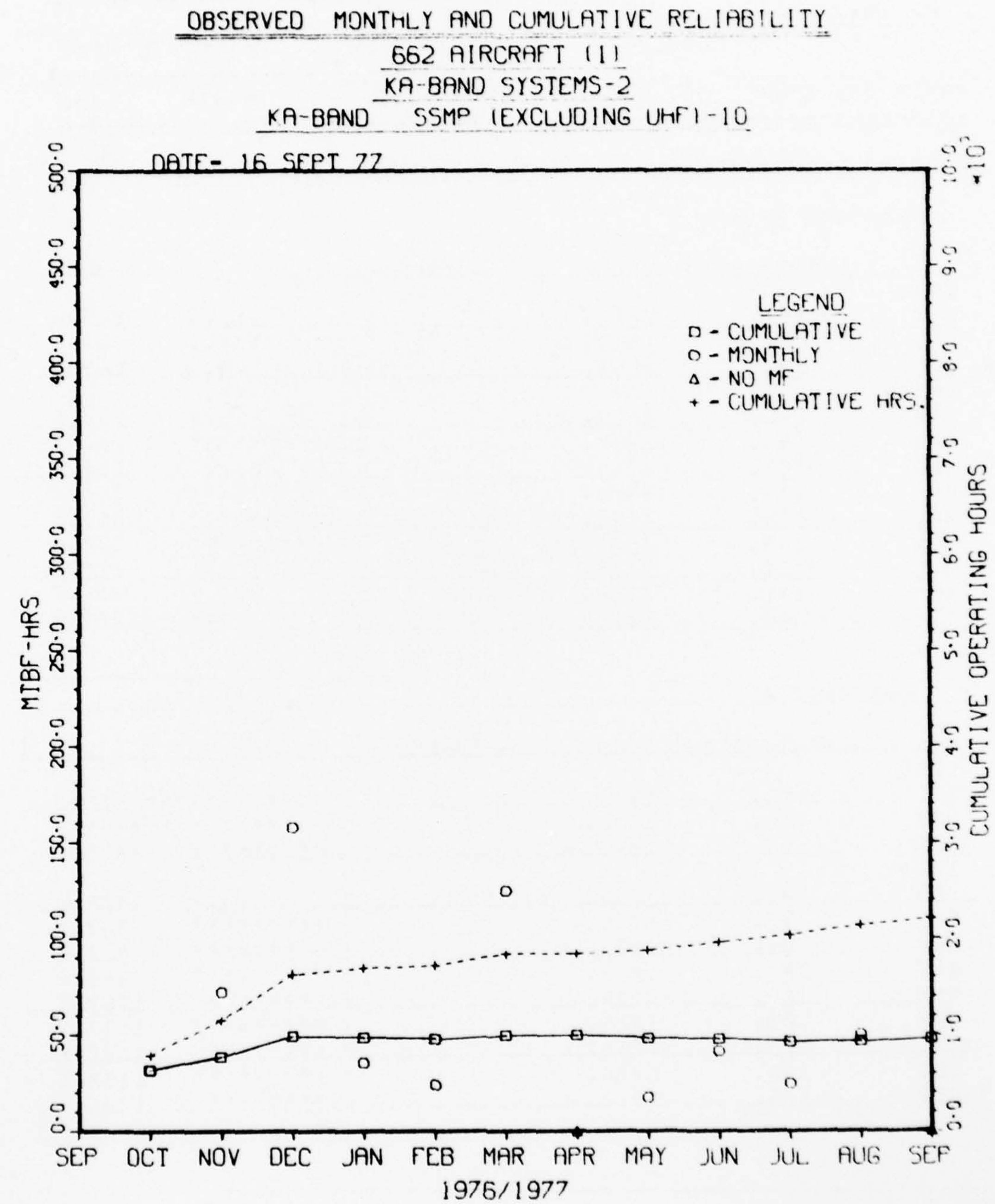



Figure 15

MODEM/Processor Group

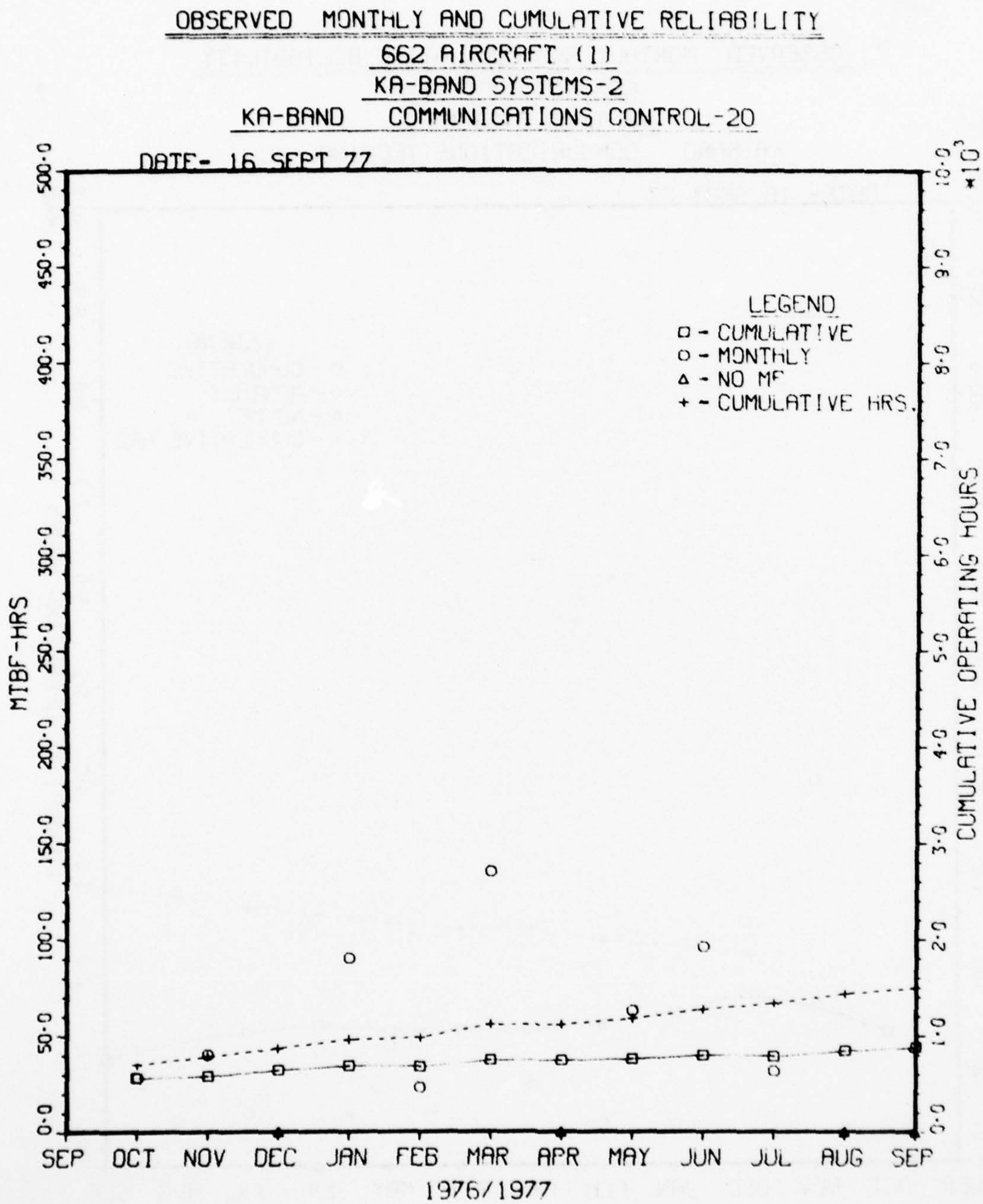



Figure 16

Communication Control Group

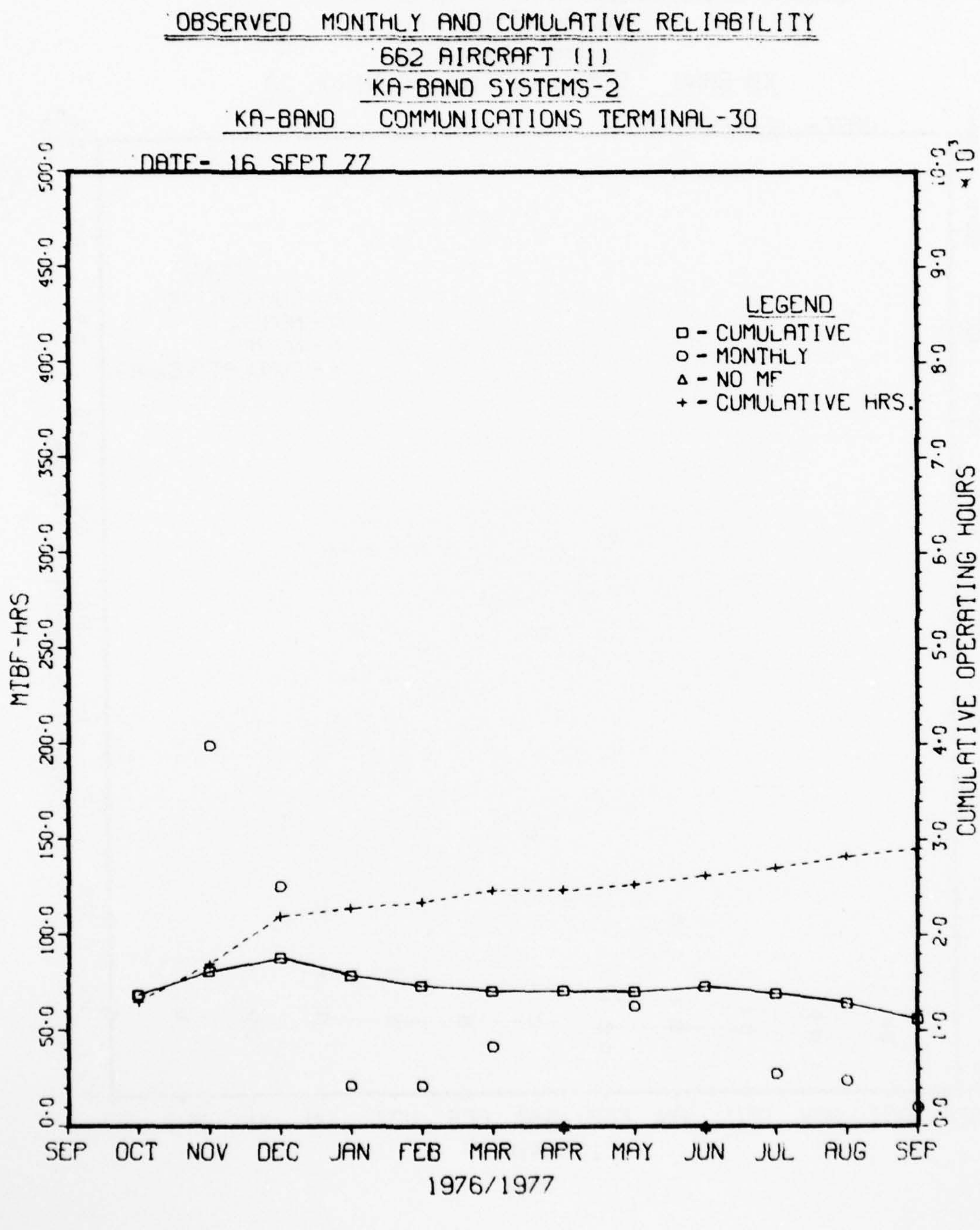



Figure 17

Communication Terminal Group

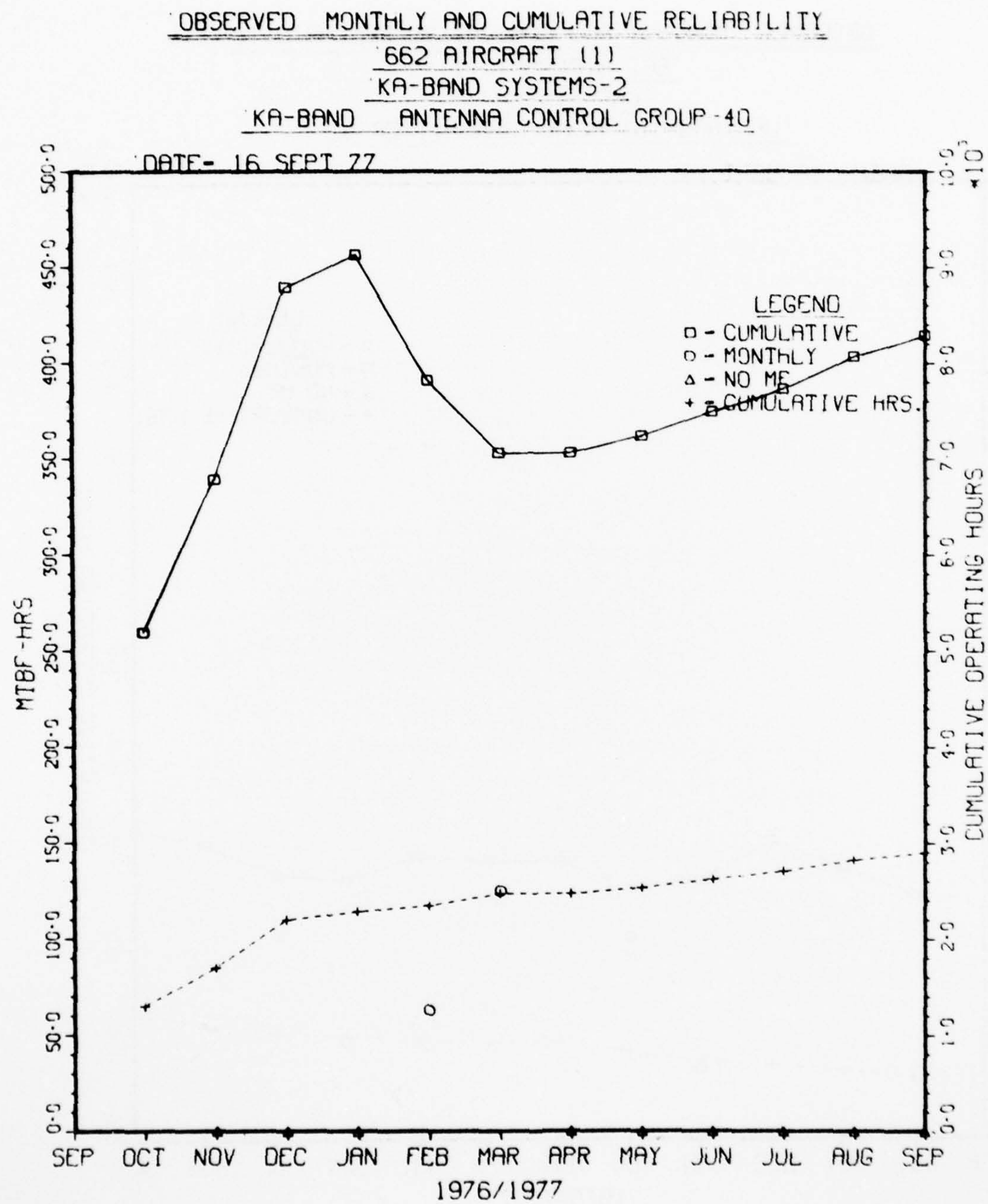



Figure 18

Antenna Control Group

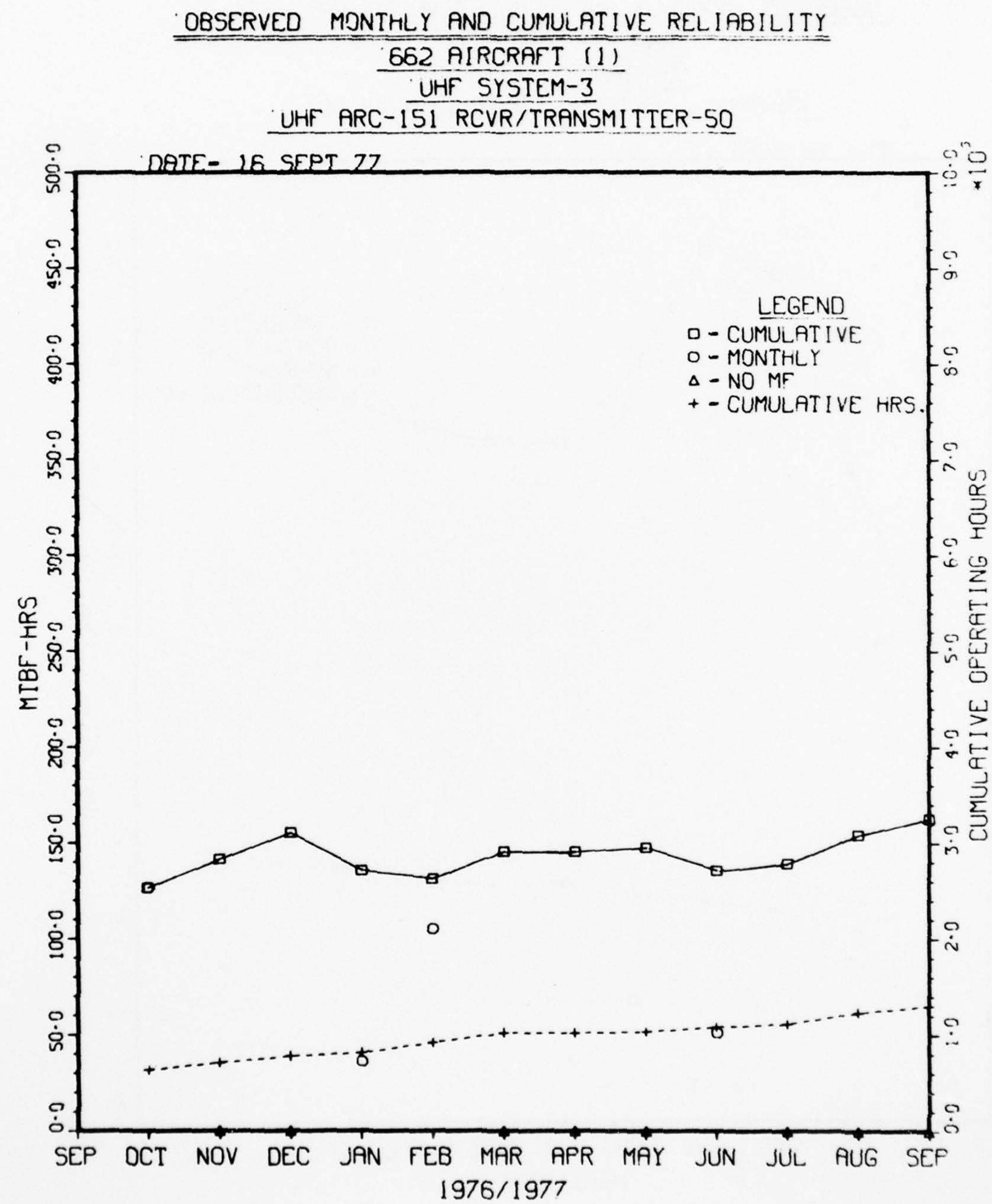



Figure 19

UHF ARC-151

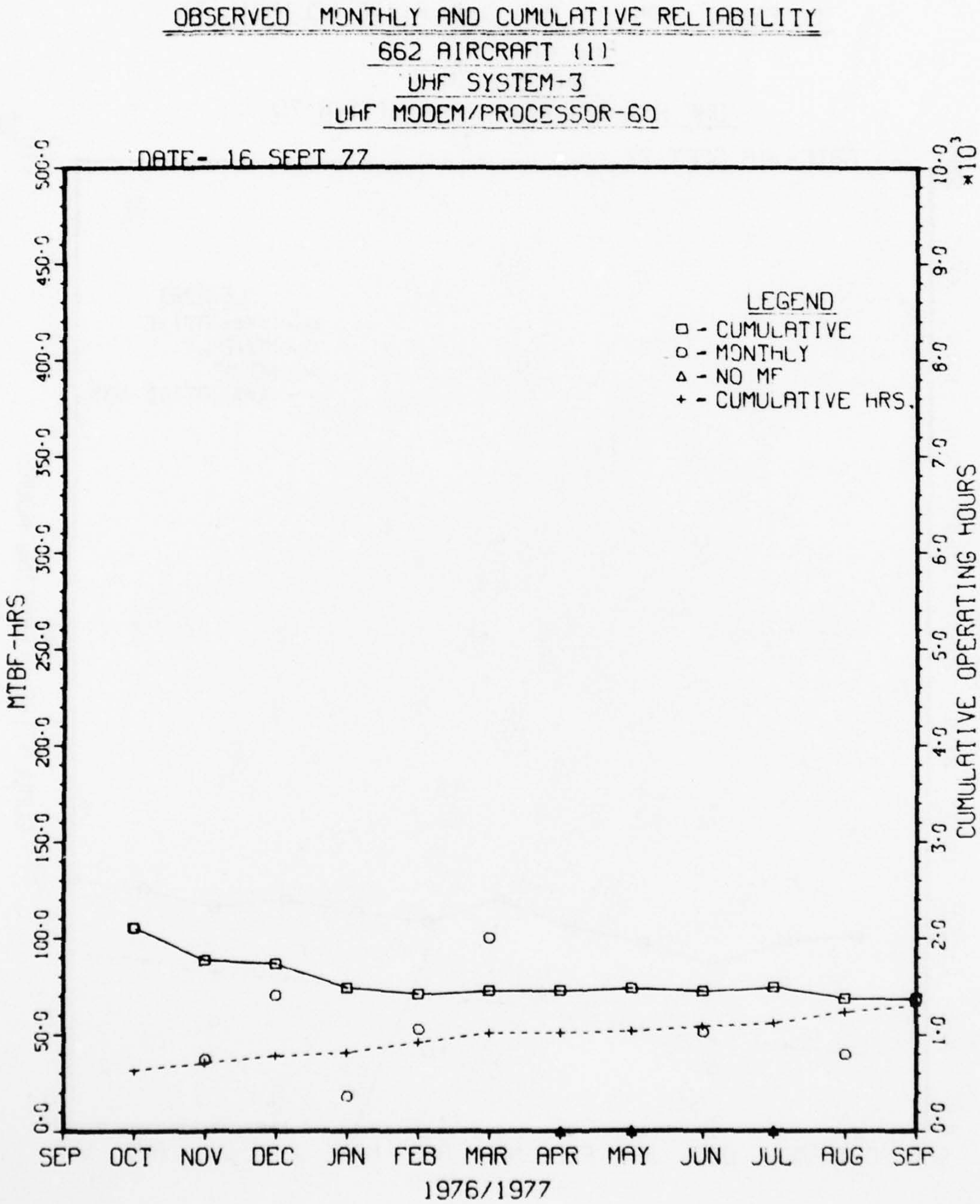



Figure 20

UHF MODEM/Processor

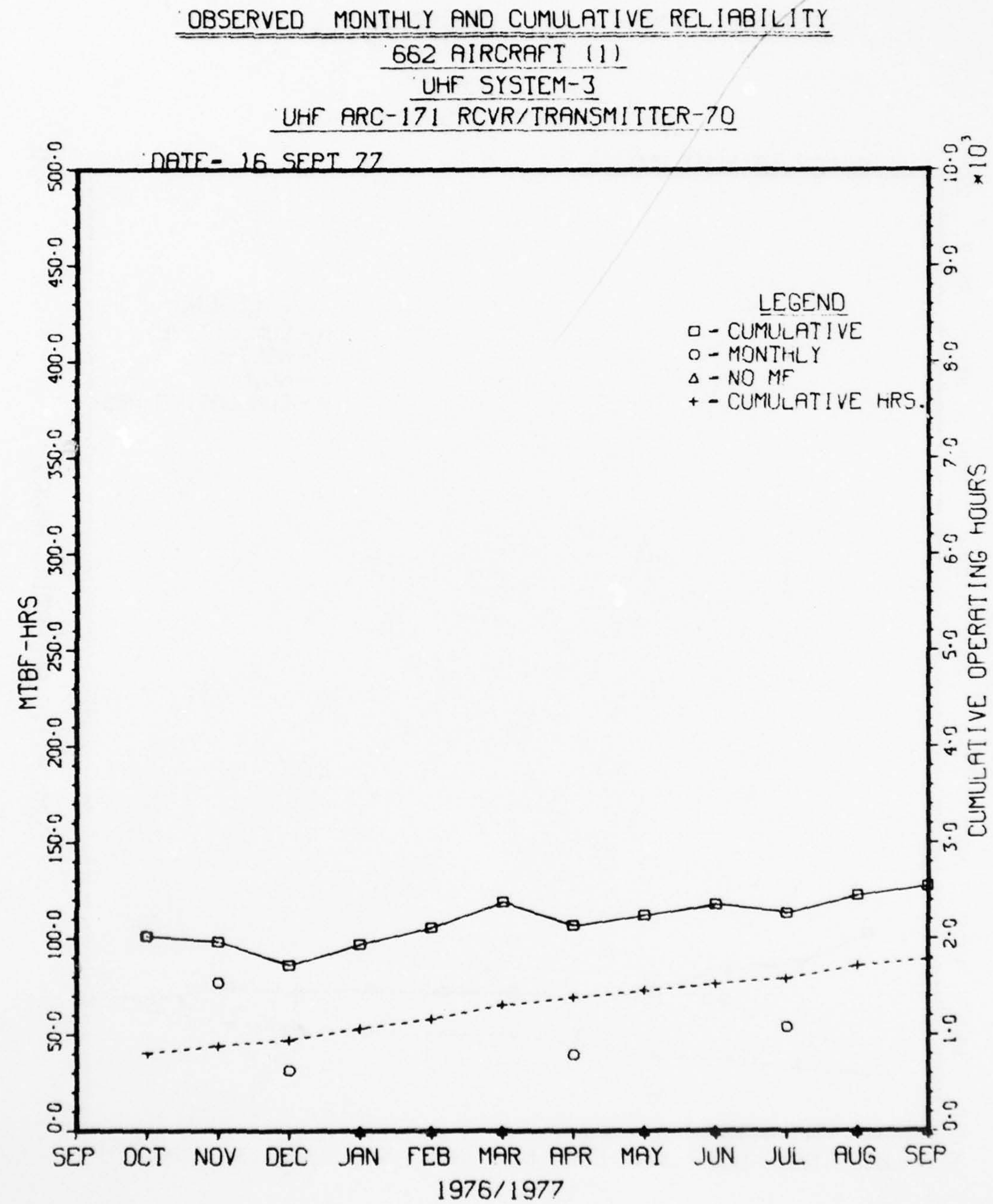



Figure 21

UHF ARC-171

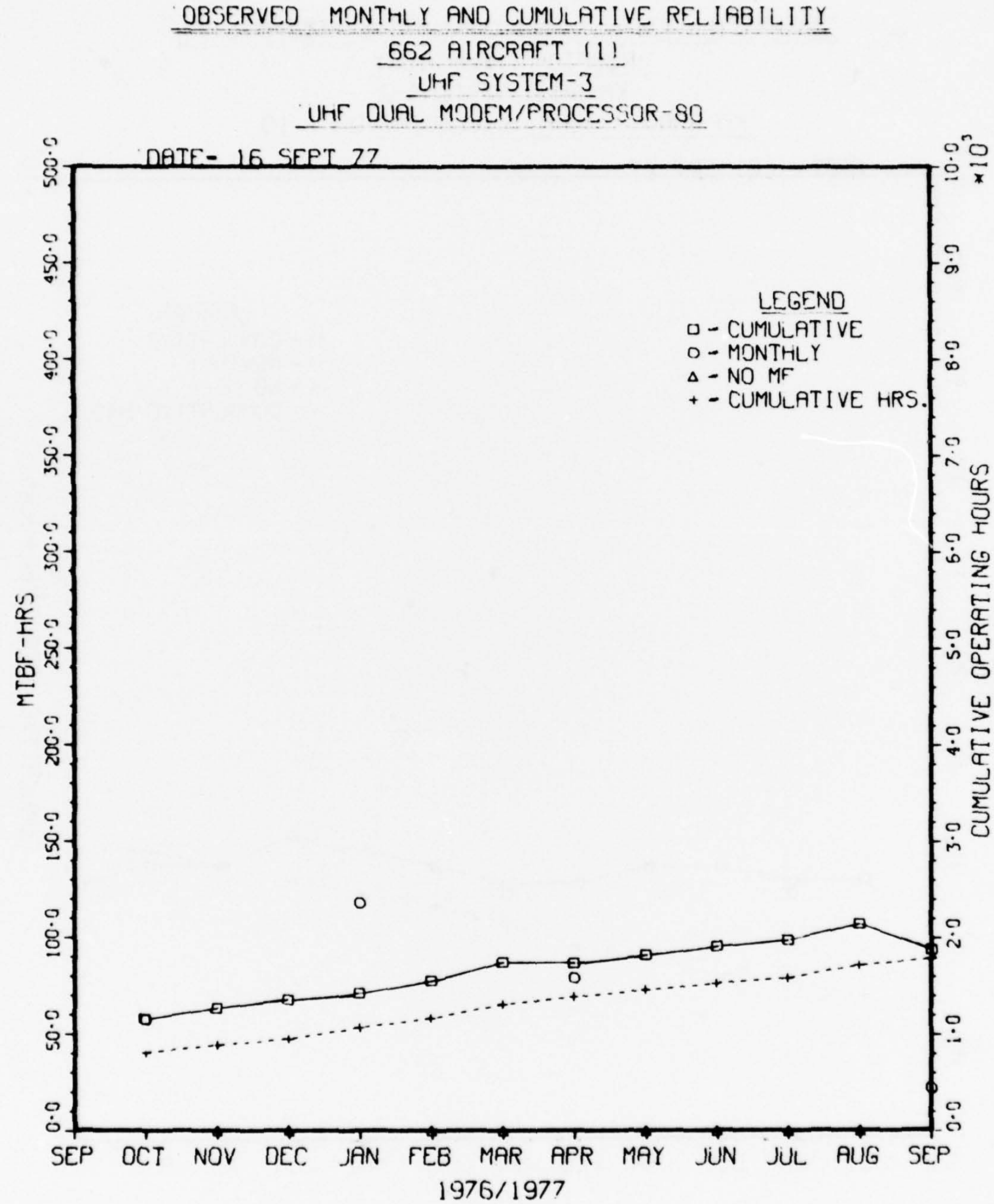



Figure 22

UHF DUAL MODEM/Processor

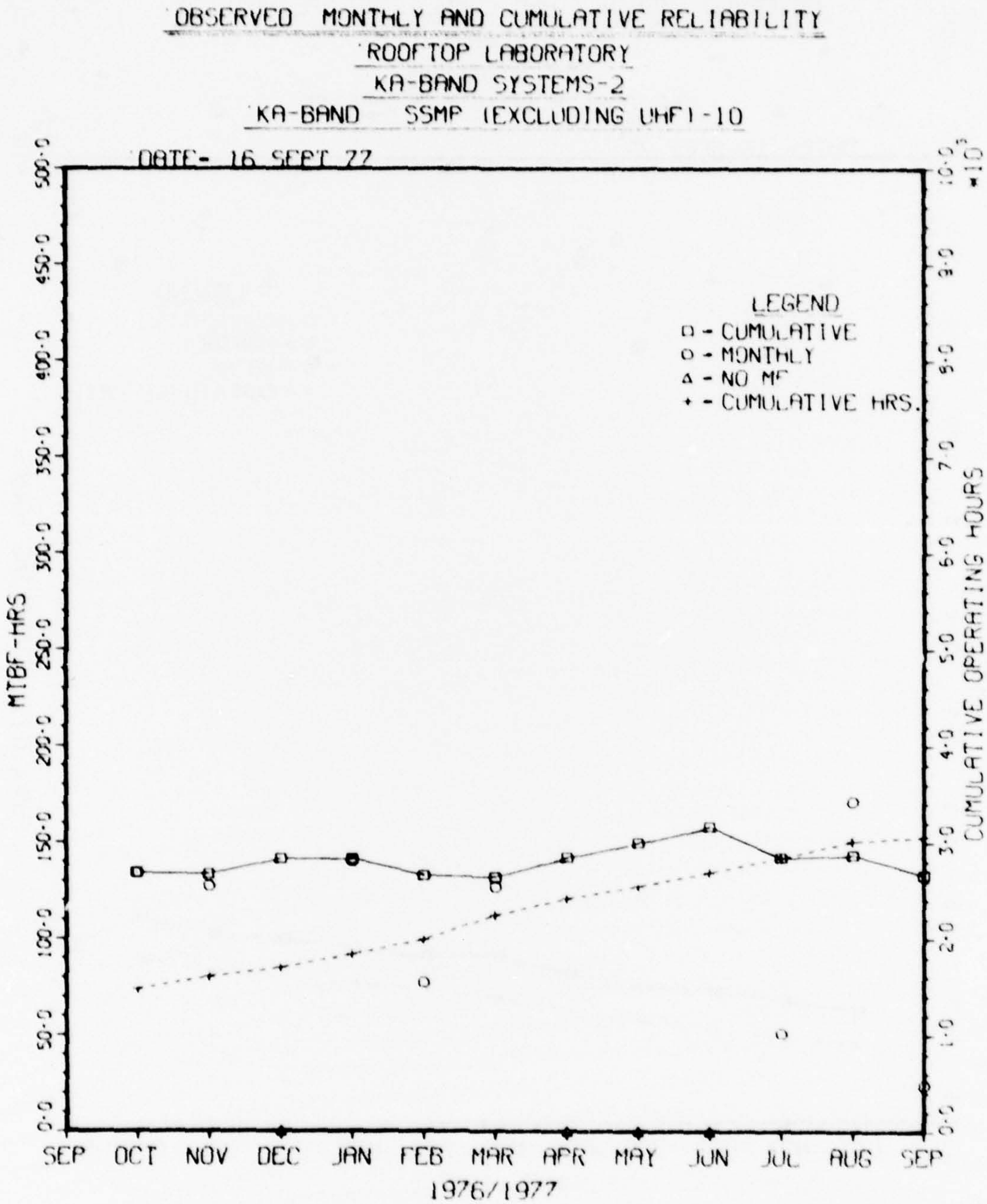



Figure 23

MODEM/Processor Group

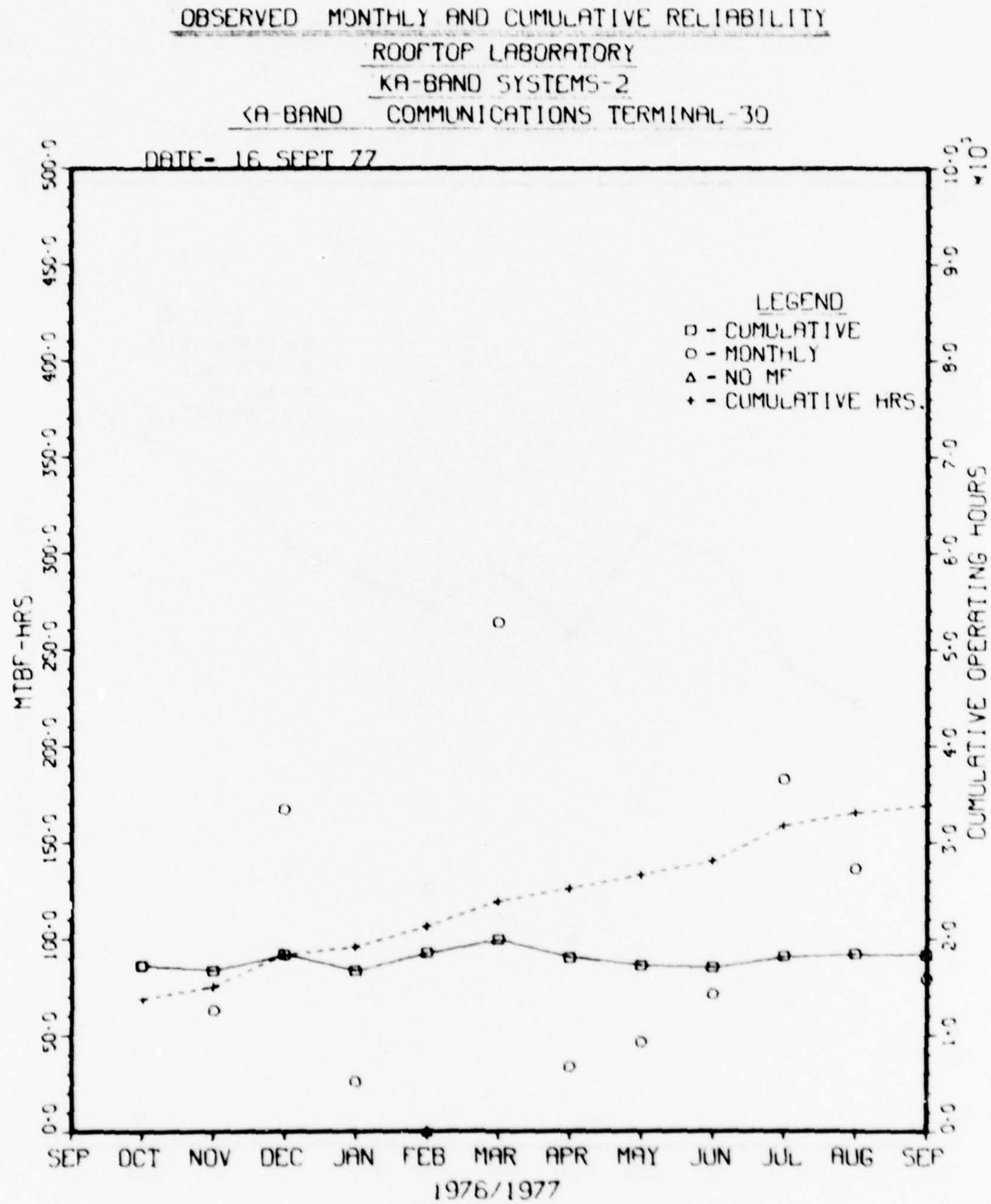



Figure 24

Communication Terminal Group

OBSERVED MONTHLY AND CUMULATIVE RELIABILITY
ROOFTOP LABORATORY
KA-BAND SYSTEMS-2
KA-BAND ANTENNA CONTROL GROUP 40

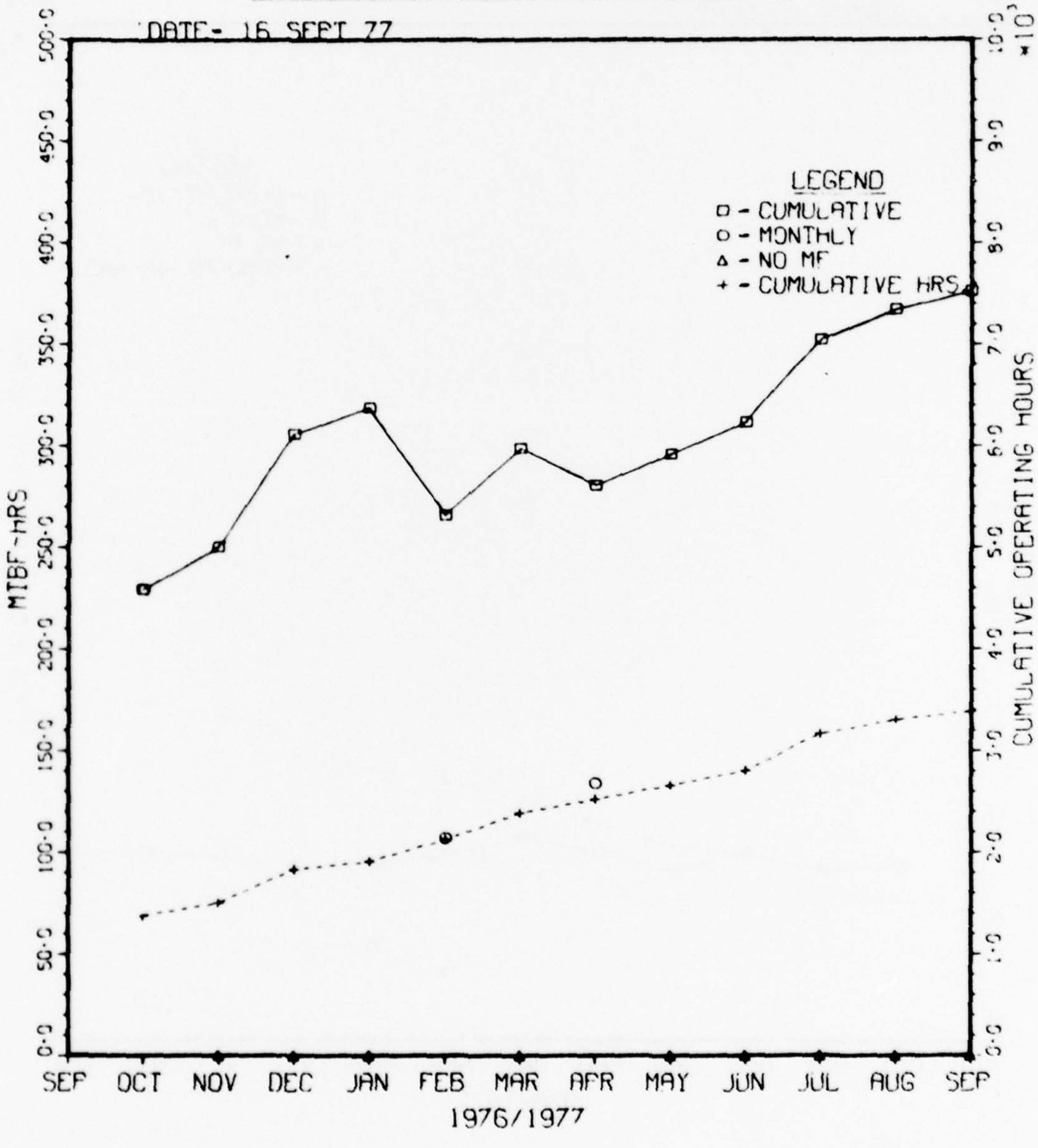



Figure 25

Antenna Control Group

OBSERVED MONTHLY AND CUMULATIVE RELIABILITY
ROOFTOP LABORATORY
UHF SYSTEM-3
UHF ARC-151 RCVR/TRANSMITTER-50

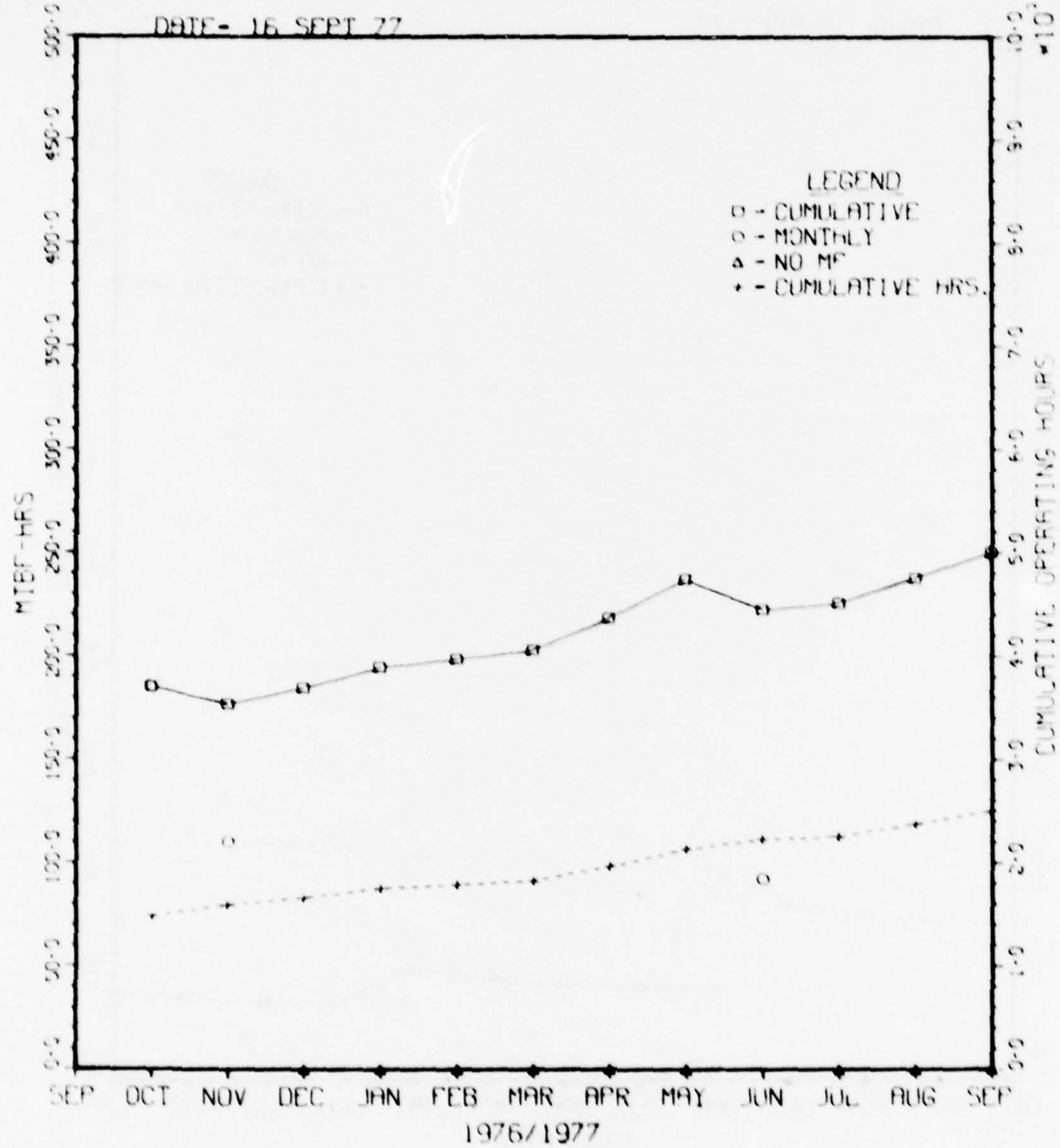



Figure 26

UHF ARC-151

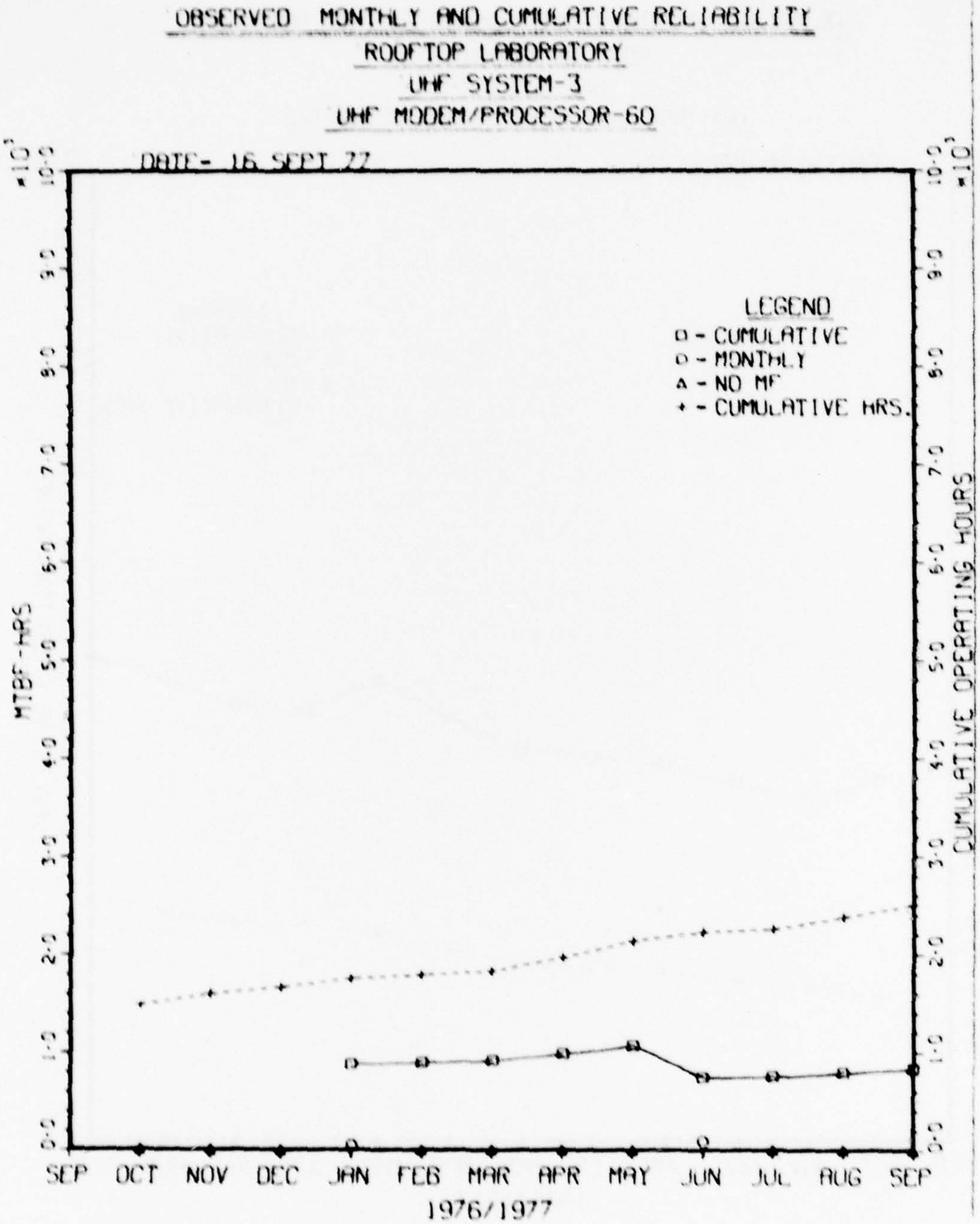



Figure 27

UHF MODEM/Processor

## APPENDIX B

### SUBGROUP MTBF EXPECTATIONS BASED ON COMPONENT REPAIR OR REPLACEMENT

A subgroup, TASRA Nr. 362 for example, is put on test at time $t_o$ and operated until failure occurs at time $t_1$. Upon failure it is assumed that the group component is instantly repaired or replaced on test where it continues to operate until failure occurs at time $t_2$. This procedure is assumed to be repeated until the elapse of a total test time T. It is further assumed that the times between failures are exponentially distributed with a true mean time between failures, MTBF, represented by $\theta$. The observed mean time between failure is given by $\bar{\theta}$, where $\bar{\theta}$ is computed as follows

$$\bar{\theta} = T/K,$$

where T is the total test time and K is the number of failures which occurred during that test time. The derivation given in the following paragraph shows that $\bar{\theta}$ is the maximum likelihood estimator of $\theta$.

Based on the assumption of the exponential distribution with mean $\theta$, it follows that the probability density that the first failure occurs at time $t_1$ is

$$P_1 = (1/\theta) \exp(-(t_1-t_0)/\theta).$$

Following repair or replacement, the probability density that the next failure occurs at time $t_2$ is

$$P_2 = (1/\theta) \exp(-(t_2-t_1)/\theta).$$

and similar expressions hold for the remaining failures. After the Kth failure has occurred, it is assumed that the subgroup operates successfully until the completion of the test at time t. The probability of the event is given by

$$P_{K+1} = \exp(-(t-t_K)/\theta).$$

The likelihood function L is then given by the product of these expressions

$$L = P_1 \ldots\ldots P_{K+1}$$

and the substitution yields

$$L = (1/\theta)^K \exp(-T/\theta)$$

where

$$T = t-t_0.$$

The maximum likelihood estimate of $\theta$ is then obtained by finding that value of $\theta$ that maximizes L. Observing that L takes on a maximum when ln L is maximized, this value is found by differentiation of the logarithm of the likelihood function

$$\ln L = -K(\ln \theta) - (T/\theta).$$

Differentiation then yields

$$d(\ln L)/d\theta = (-K/\theta) + (T/\theta^2),$$

and by equating this expression to zero it follows that

$$\bar{\theta} = T/K$$

is the maximum likelihood estimator of $\theta$ as discussed by Spradlin, Hanks and Easterday (24). The maximum likelihood estimator (MLE) according to Shooman is a flexible and powerful tool. The MLE is superior to the moment estimator and the least squares estimator (23).

The MLE has a number of good properties. This estimator provides a sufficient point estimator if a sufficient estimator exists for the problem. Also the MLE is the most efficient for a large sample size. Shooman in the preceding section of his text discusses interval estimates (confidence coefficient) as addressed in Appendix D. This gives the analyst some idea of how precise the point estimate is. MLE is clearly the first choice, since it is the only estimator which allows a simple computation of variance.

The above forms the basis for the calculation of the MTBF values as shown in the body of the report. For example, in Table 6, at the subgroup level the aircraft data for the High Voltage Power Supply (TASRA Nr. 362) had accumulated 2901 test hours and a total of 8 failures. Thus the estimated MTBF based on the observed data is 2901 divided by 8 or 363 hours. The calculations of MTBF at group and system levels are based on the models given in Table 2 and Figures 7 and 8.

APPENDIX C

# MTBF GOODNESS OF FIT TEST FOR A GROUP SUBJECT TO REPAIR OR REPLACEMENT

## THE KOLMOGROV-SMIRNOV ONE SAMPLE TEST

It was initially assumed that the probability density of the electronic component within the group follows an exponential distribution. If this is true, then reliability

$$R = \exp(-T/\theta)$$

where

$$T = \text{time in hours}$$

and

$$\theta = \text{MTBF in hours.}$$

By using the MTBF of 95.7 hours, data were generated for a theoretical exponential distribution based on cumulative failures

$$F_t(T) = 1 - \exp(-T/\bar{\theta}).$$

This was done to examine the probability of a sample being drawn from an exponential distribution. To test this theoretical distribution against the observed distribution of the sample, the Kolmogrov-Smirnov One Sample Test was used as discussed by Locks(14) and Miller and Freund (16).

$F_t(T)$ = theoretical distribution under the null hypothesis, $H_0$. For any value of T, time in hours each interval, the value of $F_t(T)$ is proportional to the number of failures that will have occurred before time T. In Table 18,

C is $F_t(T)$ and B is T.

$S_n(T) = A/N$, where A is number of observed failures occurring before time T and N is the total number of failures observed. In Table 18, C' is $S_n(T)$ and B is T.

$H_0$ = the null hypothesis that there is no significant difference between the observed sample distribution for the group of components under test and the theoretical exponential distribution. If this is true, then it is reasonable to assume that the observed sample distribution is approximately an exponential. If the sample were drawn from a population with an exponential distribution, it is expected that for every value of (T), $S_n(T)$ should be fairly close to $F_t(T)$. The largest value of $F_t(T) - S_n(T)$ is the maximum deviation of $D_m$. In Table 18, D is the difference of $F_t(T)$ and $S_n(T)$. The above procedure is discussed by Locks in his book on page 90, section titled "Goodness of Fit Analysis" (14).

Critical value of $D_m$ is determined by the size of the sample and the number of failures. See Table 17 (reference 15) for the $D_m$ value. The level of significance was set at 5%. If any D value of the test exceeds the $D_m$ value of 29%, which is the critical value of $D_m$ for a sample of 21 failures at 0.05 level of significance, the null hypothesis $H_0$ will be rejected. If $H_0$ is rejected, then it would not be reasonable to assume that the distribution of the population is exponential.

# Table 17 Critical Values for Goodness of Fit Test



## TABLE 14-2

### CRITICAL VALUES OF THE KOLMOGOROV-SMIRNOFF TEST STATISTIC

$N$ = sample size, $C$ = s-confidence level, $S$ = s-significance level

| N | C = 80% S = 20% | 90% 10% | 95% 5% | 98% 2% | 99% 1% |
|---|---|---|---|---|---|
| 1 | .900 | .950 | .975 | .990 | .995 |
| 2 | .684 | .776 | .842 | .900 | .929 |
| 3 | .565 | .636 | .708 | .785 | .829 |
| 4 | .493 | .565 | .624 | .689 | .734 |
| 5 | .447 | .509 | .563 | .627 | .669 |
| 6 | .410 | .468 | .519 | .577 | .617 |
| 7 | .381 | .436 | .483 | .538 | .576 |
| 8 | .358 | .410 | .454 | .507 | .542 |
| 9 | .339 | .387 | .430 | .480 | .513 |
| 10 | .323 | .369 | .409 | .457 | .489 |
| 11 | .308 | .352 | .391 | .437 | .468 |
| 12 | .296 | .338 | .375 | .419 | .449 |
| 13 | .285 | .325 | .361 | .404 | .432 |
| 14 | .275 | .314 | .349 | .390 | .418 |
| 15 | .266 | .304 | .338 | .377 | .404 |
| 16 | .258 | .295 | .327 | .366 | .392 |
| 17 | .250 | .286 | .318 | .355 | .38[illegible] |
| 18 | .244 | .279 | .309 | .346 | .371 |
| 19 | .237 | .271 | .301 | .337 | .361 |
| 20 | .232 | .265 | .294 | .329 | .352 |
| 22 | .221 | .253 | .281 | .314 | .337 |
| 24 | .212 | .242 | .269 | .301 | .323 |
| 26 | .204 | .233 | .259 | .290 | .311 |
| 28 | .197 | .225 | .250 | .279 | .300 |
| 30 | .190 | .218 | .242 | .270 | .290 |
| 32 | .184 | .211 | .234 | .262 | .281 |
| 34 | .179 | .205 | .227 | .254 | .273 |
| 36 | .174 | .199 | .221 | .247 | .265 |
| 38 | .170 | .194 | .215 | .241 | .258 |
| 40 | .165 | .189 | .210 | .235 | .252 |
| approximation for $N$ > 10 | $\frac{1.07}{\sqrt{N+1}}$ | $\frac{1.22}{\sqrt{N+1}}$ | $\frac{1.36}{\sqrt{N+1}}$ | $\frac{1.52}{\sqrt{N+1}}$ | $\frac{1.63}{\sqrt{N+1}}$ |

**Notes:**

(1) The approximate formula has an error less than about ± 2% of the actual value.

(2) This K-S statistic is compared to the $U_{max}$ = max $|Cdf_{actual} - Cdf_{hypothesis}|$ for all sample points. If the K-S statistic is no more than $U_{max}$, the hypothesis is accepted at the appropriate s-confidence level. The Table gives the 2-sided statistic.

(3) This K-S statistic can also be used to put a s-confidence band around a hypothesized $Cdf$.

Table 18 Goodness of Fit Test RT-30 Communication Terminal Group

STO-21 21 N, Total number of failures
STO-23 99.7 θ, MTBF hours
STO-20 29% Critical Value of K-S Test Statistic

| E | A | B | C | C' | D | E' | D' | A' | B' |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 3 | 25.7 | 23.6 | 14.3 | +9.3 | 3.25 | -1.87 | --- | 0.57 |
| 2 | 4 | 33.5 | 29.5 | 33.3 | -3.8 | 3.51 | -0.90 | -3.12 | -0.02 |
| 3 | 3 | 46.3 | 38.4 | 47.6 | -9.2 | 3.84 | -0.44 | -1.58 | +0.37 |
| 4 | 2 | 63.0 | 48.2 | 57.1 | -8.9 | 4.14 | -0.17 | -1.11 | +0.68 |
| 5 | 2 | 71.0 | 52.4 | 66.7 | -14.3 | 4.26 | +0.09 | -0.75 | +1.14 |
| 6 | 1 | 79.0 | 56.2 | 71.4 | -15.2 | 4.37 | +0.22 | -0.59 | +1.70 |
| 7 | 1 | 136.0 | 75.9 | 76.2 | -0.3 | 4.91 | +0.36 | -0.45 | +1.09 |
| 8 | 2 | 167.0 | 82.5 | 85.7 | -3.2 | 5.12 | +0.67 | -0.18 | +0.65 |
| 9 | 2 | 182.5 | 85.2 | 95.2 | -10.0 | 5.21 | +1.11 | +0.08 | +0.35 |
| 10 | 1 | 478.0 | 99.3 | 100.0 | -0.7 | 6.17 | +2.22 | +0.21 | +0.21 |

Slope 1.23

Y intercept -5.36 at X = 0

$D_{max}$ = 29% at 95% Confidence level (Table 17. N = 21)

The value of D (Table 18, maximum of Column D) is 15.2% which is smaller than 29%; therefore the hypothesis that there is no significant difference between the observed sample distribution of the failures in the group under test and the theoretical exponential distribution is not rejected. Since there is no significant difference at the 0.05 significance level, it is reasonable to assume that the sample came from a population with an exponential distribution.

The above equations were programmed, (Table 19), on the Texas Instrument, Inc. (TI-58) Programmable Calculator (26).

Table 19 Goodness of Fit Test Program Coding for the TI-58 Programmable Calculator

| STEP | PROCEDURE | ENTER | PRESS | | | DISPLAY |
|---|---|---|---|---|---|---|
| 1 | Clear Program Memory | | 2nd | CP | | |
| 2 | Enter Learn Mode | | LRN | | | 000-00 |
| 3 | Enter K-S, Weibull Test Program | | | | | |
| 4 | Exit Learn Mode | | LRN | | | 0 |
| 5 | Enter Total Number of Failures | N | STO | 21 | | N |
| 6 | Enter MTBF | Hours | STO | 23 | | Hours |
| 7 | Enter Critical Value fm Table 17 | %CV | STO | 20 | | %CV |
| 8 | Enter Failure each interval | $n_i$ | A | | | $n_i$ |
| 9 | Enter Time each interval | t hours | B | | | t hours |
| 10 | Compute Exponential $F_t(T)$ | | C | | | $\%F_t(T)$ |
| 11 | Compute Observed $S_N(T)$ | | 2nd | C | | $\%S_N(T)$ |
| 12 | Compute Difference $F_t(T) - S_N(T)$ | | D | | | %V |
| 13 | Compute Weibull (X) Time each interval | | 2nd | E | | ln t hrs |
| 14 | Compute Weibull (Y) Cumulative % Failures | | 2nd | D | | $\% S_o(T)$ |
| 15 | Compute Weibull (Y) Lower bounds | | 2nd | A | | $\% S_1(T)$ |
| 16 | Compute Weibull (Y) Upper bounds | | 2nd | B | | $\% S_u(T)'$ |
| 17 | Compute Statistic Sum | | E | | | i = 1,2,--,n |
| 18 | Compute Y intercept and Slope $\beta$ | 2nd | OP | 12 | $X \rightleftarrows t$ | $\beta$ |

Table 19 Program Coding (Continued)

| LOC | CODE | KEY | COMMENTS | LOC | CODE | KEY | COMMENTS |
|---|---|---|---|---|---|---|---|
| 00 | 42 | STO | | 04 | 95 | = | |
| | 21 | 21 | | | 65 | x | |
| | 42 | STO | | | 01 | 1 | |
| | 23 | 23 | | | 00 | 0 | |
| | 76 | lbl | | | 00 | 0 | |
| | 11 | A | | 05 | 95 | = | |
| | 44 | SUM | | | 42 | STO | |
| | 22 | 22 | | | 26 | 26 | $\%S_N(T)$ |
| | 91 | R/S | | | 91 | R/S | |
| | 76 | lbl | | | 76 | lbl | |
| 01 | 12 | B | | | 14 | D | |
| | 42 | STO | | | 43 | RCL | |
| | 24 | 24 | | | 25 | 25 | |
| | 91 | R/S | | | 75 | - | |
| | 76 | lbl | | | 43 | RCL | |
| | 13 | C | | 06 | 26 | 26 | |
| | 43 | RCL | | | 95 | = | |
| | 23 | 23 | | | 91 | R/S | % V |
| | 35 | 1/x | | | 76 | lbl | |
| | 94 | +/- | | | 10 | E' | |
| 02 | 65 | x | | | 43 | RCL | |
| | 43 | RCL | | | 24 | 24 | |
| | 24 | 24 | | | 23 | lnx | |
| | 95 | = | | | 42 | STO | |
| | 22 | INV | | | 10 | 10 | X(T) |
| | 23 | lnx | | 07 | 91 | R/S | |
| | 75 | - | | | 76 | lbl | |
| | 01 | 1 | | | 19 | D' | |
| | 95 | = | | | 53 | ( | |
| | 94 | +/- | | | 53 | ( | |
| 03 | 65 | x | | | 43 | RCL | |
| | 01 | 1 | | | 26 | 26 | |
| | 00 | 0 | | | 75 | - | |
| | 00 | 0 | | | 71 | SBR | |
| | 95 | = | | | 33 | $x^2$ | |
| | 42 | STO | | 08 | 42 | STO | |
| | 25 | 25 | $\%F_t(T)$ | | 11 | 11 | Y(T) |
| | 91 | R/S | | | 91 | R/S | |
| | 76 | lbl | | | 76 | lbl | |
| | 18 | C' | | | 15 | E | |
| 04 | 43 | RCL | | | 43 | RCL | |
| | 22 | 22 | | | 10 | 10 | |
| | 55 | ÷ | | | 32 | $x \rightleftarrows t$ | |
| | 43 | RCL | | | 43 | RCL | |
| | 21 | 21 | | | 11 | 11 | |

Table 19 Program Coding (Continued)

| LOC | CODE | KEY | COMMENTS | LOC | CODE | KEY | COMMENTS |
|---|---|---|---|---|---|---|---|
| 090 | 78 | Σ+ | | 13 | 43 | RCL | |
| | 91 | R/S | | | 26 | 26 | |
| | 76 | lbl | | | 85 | + | |
| | 33 | $x^2$ | | | 43 | RCL | |
| | 01 | 1 | | | 20 | 20 | |
| | 00 | 0 | | 14 | 54 | ) | |
| | 00 | 0 | | | 75 | - | |
| | 93 | . | | | 71 | SBR | |
| | 00 | 0 | | | 33 | $x^2$ | |
| | 01 | 1 | | | 42 | STO | |
| 100 | 54 | ) | | | 28 | 28 | |
| | 50 | $\lvert x \rvert$ | | | 91 | R/S | |
| | 35 | 1/x | | | 00 | | |
| | 65 | x | | | 00 | | |
| | 01 | 1 | | | 00 | | |
| | 00 | 0 | | | 00 | | |
| | 00 | 0 | | | | | |
| | 54 | ) | | | | | |
| | 23 | lnx | | | | | |
| | 23 | lnx | | | | | |
| 110 | 92 | INV-SBR | | | | | |
| | 42 | STO | | | | | |
| | 20 | 20 | | | | | |
| | 76 | lbl | | | | | |
| | 16 | A' | Lower | | | | |
| | 53 | ( | | | | | |
| | 53 | ( | | | | | |
| | 53 | ( | | | | | |
| | 43 | RCL | | | | | |
| | 26 | 26 | | | | | |
| 120 | 75 | - | | | | | |
| | 43 | RCL | | | | | |
| | 20 | 20 | | | | | |
| | 54 | ) | | | | | |
| | 75 | - | | | | | |
| | 71 | SBR | | | | | |
| | 33 | $x^2$ | | | | | |
| | 42 | STO | | | | | |
| | 27 | 27 | | | | | |
| | 91 | R/S | | | | | |
| 130 | 76 | lbl | | | | | |
| | 17 | B' | Upper | | | | |
| | 53 | ( | | | | | |
| | 53 | ( | | | | | |
| | 53 | ( | | | | | |

## THE WEIBULL DISTRIBUTION

Using the Weibull distribution probability plotting approach, compare the observed distribution of the sample ($S_n(T)$) to that of the exponential distribution ($F_t(T)$). The Weibull distribution is closely related to the exponential but has two additional parameters, the shape parameter and the location parameter (8). Thus, instead of a single constant failure rate $\lambda$ a variety of hazard situations can be addressed. For a given Weibull distribution the failure rate can continually be of increasing, constant, or decreasing values, exhibiting all three phenomena of the so called bathtub curve of burn-in, constant failure rate or wearout. The usefulness of the Weibull distribution is the relative ease it affords of probability plotting to estimate these parameters, detect outliers (or wild points), and perform goodness of fit analysis (14). To further increase the ease of probability plotting the Weibull distribution, a program (Table 19) using the TI-58 programmable calculator was devised so that it will allow the use of linear graph instead of the special Weibull distribution probability paper for a straight-line Weibull fit (26).

The input and output designations of the program are as follows:

A = number of failures each interval,

B = T, time in hours,

C = % $F_t(T)$,

$C' = \%\ S_n(T),$

$D = (F_t(T) - S_n(T)),$

$E' = (X), \quad (\ln(T - X_0))$

$D' = (Y), \quad (\ln(-\ln\ (1 - S_n(T))))$

$A'$ = Lower limit of (Y), $(D_m - Y)$

$B'$ = upper limit of (Y), $(D_m - Y)$

E = computed statistic SUM

After the statistic SUM, as given in Table 18, has been computed for E, when i reaches ten, the slope $\beta$ and intercept $\gamma$ can be computed using program of Table 19. For this example, the Y intercept is -5.36 with X of zero and a slope $\beta$ of 1.23.

Initially an exponential distribution with time (T) for each failure was derived by assuming a constant failure rate, $\lambda=1/\bar{\theta}$, as discussed in Appendix B. The reliability R(T), the probability that the failure occurs after (T) is

$$R(T) = \exp\ (-\lambda T), T \geq 0.$$

By taking the natural logarithm of the reliability function R(T) the equation

$$-\ln R(T) = \lambda T$$

can be plotted as a straight line on semi-logarithm paper with an intercept at the origin and a slope of $\lambda$ as discussed by Locks (14).

To obtain a straight line Weibull distribution with a parameter $\beta$ and location parameter $X_0$, define $\bar{\theta}=1/\lambda$ and subtract a quantity $X_0$, which is greater or equal to zero,

from (T); the resulting equation is a reliability function

$$R(T) = \exp -((T-X_0)/\bar{\theta})^{\beta},$$

Taking the natural logarithm of the reliability function results in

$$-\ln R(T) = ((T-X_0)/\bar{\theta})^{\beta}.$$

The natural logarithm of the above then results in a straight line relationship on lnln versus ln graph paper. Therefore

$$\ln(-\ln R(T)) = \beta \ln (T - X_0) - \beta \ln \bar{\theta}$$

and is related to the straight line

$$Y = X + G$$

wherein

$$Y = \ln (-\ln R(T),$$

$$X = \ln (T - X_0),$$

$$G = \beta \ln(\bar{\theta})$$

with $\beta$ as the slope of the line, and G as the Y intercept at X of zero. This approach was taken in Figure 28 to augment the findings under the K-S One Sample Test. These equations were programmed, Table 19, on the TI-58 programmable calculator and resulted in the capability to use linear graph paper (27). Figure 28, the K-S Goodness Fit Test for the RT-30 Communication Group, shows that with the data plotted from Table 18, the observed data, %Sn (T), with slope of 1.23 is well within the upper and lower bounds of B' and A'. A' and B' are based on the $D_m$ critical values determined in K-S one sample test.

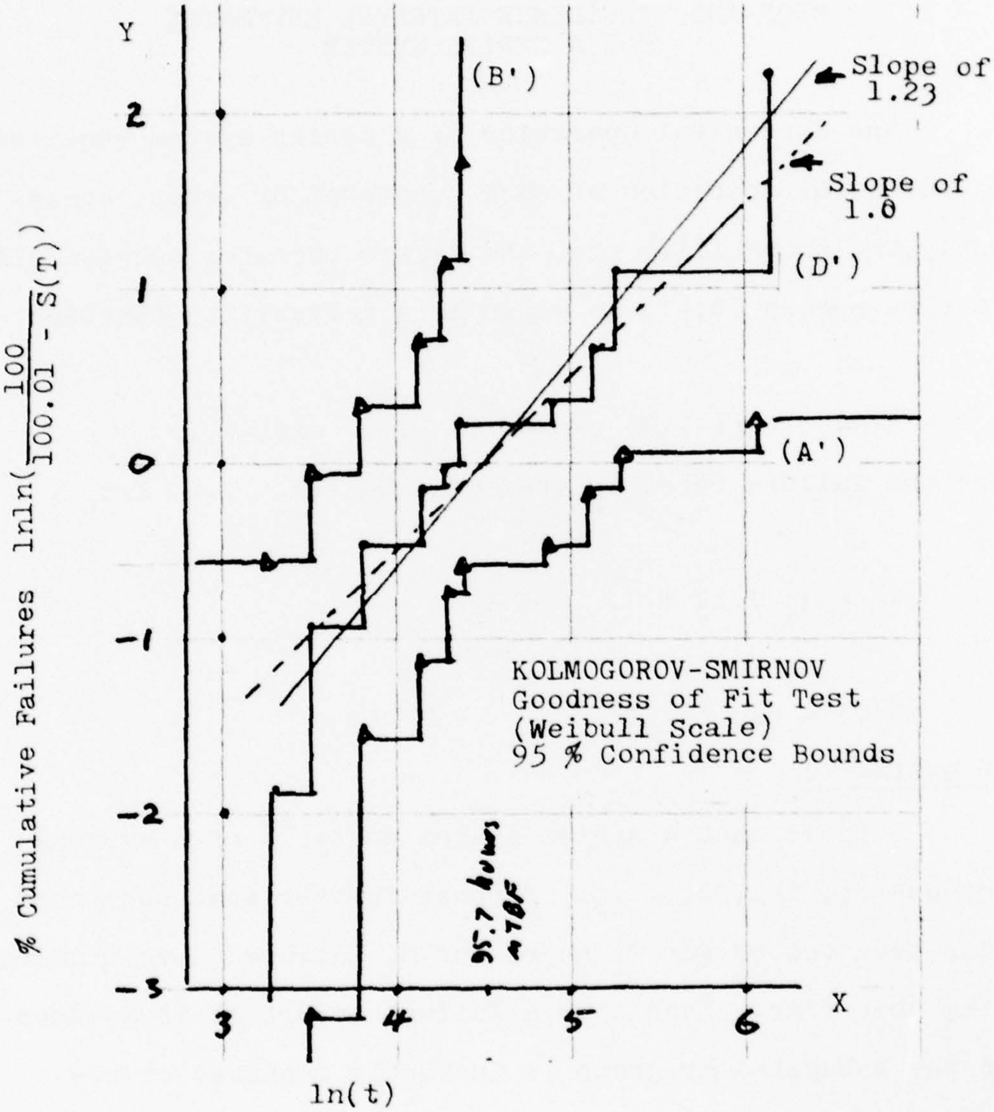



Figure 28

RT-30 Communication Terminal Group

## APPENDIX D

## MTBF AND CONFIDENCE INTERVAL ESTIMATES FOR A SERIES SYSTEM

The successful operation of a series system requires the successful operation of each subsystem or group, consequently the probability that the system operates successfully in a time period (0, T) is given as a reliability function

$$R(T) = \exp(-\lambda_1 T)\ \exp(-\lambda_2 T)\ \ldots\ \exp(-\lambda_n T)$$

where the failure rates $\lambda_i$ are equal to $1/\theta_i \ \ldots\ 1/\theta_n$ .

Thus

$$\lambda_s = \lambda_1 + \lambda_2 + \ \ldots\ + \lambda_n$$

and

$$R(T) = \exp\ (-\lambda_s T)$$

MTBF ESTIMATES

Suppose that a series system consists of n systems or groups $S_i$, i=1, 2, ...n. Suppose further that subsystem $S_i$ has been tested for $T_i$ hours and $N_i$ failures have occurred during that time. Each time a failure occurs it is assumed that the subsystem or group is instantly repaired or replaced in operation. It is also assumed that the time between failures is exponentially distributed, with $\theta_i$ denoting MTBF for group i. Under these assumptions estimates of MTBF for each group are obtained from the test results as shown.

$$\overline{\theta}_i = T_i/N_i \ ,\ i = 1, 2, \ldots n$$

Next an estimate of $\theta$ for the series system together with an upper and lower confidence limit is computed (25). To compute the upper and lower confidence limit ($\theta_U$ and $\theta_L$), it is required that the system be considered operating for a fixed time T. A suitable reference time may be obtained by setting T equal to the minimum test time for a subsystem or group.

$$T = Min(T_i)$$

The lower confidence limit $\theta_L$ increases with T and approaches $\theta$ as T approaches infinity. Therefore, if the test time is taken to be larger than the minimum for the group then a less conservative lower bound (larger MTBF) is obtained for $\theta$. This suggests that the reference time should be taken within the range of time actually used in testing the subsystem or group.

CONFIDENCE INTERVAL ESTIMATES

In section 5.11 of Reference 28, VonAlven presents two situations for estimating a confidence interval for an exponential distribution. One situation is when the test is run until a preassigned number of failures occur and the other situation is when the test is stopped after a number of test hours have been accumulated. The formula for the confidence interval, as discussed by VonAlvern, employs the $X^2$ (chi square) distribution. The general notation used is $X^2$ (p, d) wherein p is a function of the confidence coefficient and d is the degrees of freedom as a function of the

number of failures. Thus, the following Chi-Square formulas were used to estimate the confidence intervals for the parameters of an exponential distribution in which the failures were repaired or replaced.

$$\theta_U = 2N\bar{\theta}/X^2(\alpha/2), \text{ upper limit}$$

$$\theta_L = 2N\bar{\theta}/X^2(1 - (\alpha/2)), \text{ lower limit}$$

where

$N$ = Number of failures,

$DF$ = Degrees of Freedom = $2N$

and

$\alpha = 0.05$, significance level for a 95% confidence interval. A formula on Table 6-2 of Reference (18), titled "Percentiles of the Chi-Square Distribution", gives a good approximation for $X^2(p, d)$ in terms of the standard normal variate Z. Therefore for the upper limit

$$X^2(\alpha/2) = DF\left(1 - \frac{2}{9(DF)} - Z\left(\frac{2}{9(DF)}\right)^{1/2}\right)^3$$

and for the lower limit

$$X^2(1 - (\alpha/2)) = DF\left(1 - \frac{2}{9(DF)} + Z\left(\frac{2}{9(DF)}\right)^{1/2}\right)^3$$

Let Z = 1.97, the Z value for two sided symmetrical upper and lower confidence limits. A program, Table 20, was formulated for the TI-58 programmable calculator based on the above formulas (26).

Table 20 Confidence Interval Program Coding for the TI-58 Programmable Calculator

| STEP | PROCEDURE | ENTER | PRESS | | | DISPLAY |
|---|---|---|---|---|---|---|
| 1 | Clear Program Memory | | 2nd | CP | | |
| 2 | Enter Learn Mode | | LRN | | | 000-00 |
| 3 | Enter Confidence Interval Program | | | | | |
| 4 | Exit Learn Mode | | LRN | | | 0 |
| 5 | Enter Total Number of Failures | N | A | | | 2N |
| 6 | Enter MTBF | Hours | B | | | Hours |
| 7 | Enter Z value | Z | STO | 04 | | Z |
| 8 | Start Calculation | | C | | | ----- |
| 9 | Compute Upper Confidence Limit | | D | | | MTBF Upper |
| 10 | Compute Lower Confidence Limit | | E | | | MTBF Lower |
| 11 | Clear Memory for next problem | | 2nd | CM's | CLR | 0 |

Table 20 Program Coding (Continued)

| LOC | CODE | KEY | COMMENTS | LOC | CODE | KEY | COMMENTS |
|---|---|---|---|---|---|---|---|
| 00 | 76 | lbl | | 04 | 75 | - | |
| | 11 | A | | | 43 | RCL | |
| | 65 | x | | | 06 | 06 | |
| | 02 | 2 | | | 54 | ) | |
| | 95 | = | | | 45 | $Y^x$ | |
| | 42 | STO | | 05 | 03 | 3 | |
| | 01 | 01 | | | 65 | x | |
| | 91 | R/S | | | 43 | RCL | |
| | 76 | lbl | | | 01 | 01 | |
| | 12 | B | | | 95 | = | |
| 01 | 42 | STO | | | 35 | 1/x | |
| | 02 | 02 | | | 65 | x | |
| | 91 | R/S | | | 43 | RCL | |
| | 42 | STO | | | 01 | 01 | |
| | 04 | 04 | | | 65 | x | |
| | 76 | lbl | | 06 | 43 | RCL | |
| | 13 | C | | | 02 | 02 | |
| | 43 | RCL | | | 95 | = | |
| | 01 | 01 | | | 91 | R/S | |
| | 65 | x | | | 76 | lbl | |
| 02 | 09 | 9 | | | 15 | E | Lower |
| | 95 | = | | | 53 | ( | |
| | 35 | 1/x | | | 43 | RCL | |
| | 65 | x | | | 06 | 06 | |
| | 02 | 2 | | | 85 | + | |
| | 95 | = | | 07 | 01 | 1 | |
| | 42 | STO | | | 75 | - | |
| | 05 | 05 | | | 43 | RCL | |
| | 43 | RCL | | | 05 | 05 | |
| | 05 | 05 | | | 54 | ) | |
| 03 | 34 | $x^2$ | | | 45 | $Y^x$ | |
| | 65 | x | | | 03 | 3 | |
| | 43 | RCL | | | 65 | x | |
| | 04 | 04 | | | 43 | RCL | |
| | 95 | = | | | 01 | 01 | |
| | 42 | STO | | 08 | 95 | = | |
| | 06 | 06 | | | 35 | 1/x | |
| | 91 | R/S | | | 65 | x | |
| | 76 | lbl | | | 43 | RCL | |
| | 14 | D | Upper | | 01 | 01 | |
| 04 | 53 | ( | | | 65 | x | |
| | 01 | 1 | | | 43 | RCL | |
| | 75 | - | | | 02 | 02 | |
| | 43 | RCL | | | 95 | = | |
| | 05 | 05 | | | 91 | R/S | |

EXAMPLE PROBLEM

Given: The Ka-Band Communication Terminal (RT-30) located on the rooftop experienced 21 failures after 2010 hours of test time elapsed. The problem is to estimate the mean life $\theta$ and the two-sided symmetrical upper and lower confidence limits on the mean life with a confidence interval of 95%.

Steps:

1. Tabulate the test results, T = 2010 hours and N = 21 failures.
2. Compute the estimated MTBF, $\bar{\theta}$ = 95.7 hour.
3. Calculate the symmetrical confidence level, C = 95%. C' = 97.5% and 1-C' = 2.5%, therefore Z = 1.97 taken from a normal distribution function table.
4. Calculate the upper and lower confidence limits for the 95% confidence level, using the TI-58 program. Enter STO-04 = 1.97 for the Z value, enter A = 21 and B = 95.7. Key C initiates the program. The computed values are D = 154.7 for the upper limit and E = 65.1 for the lower limit.
5. Make the confidence statement that

$$154.7 \geqq \theta \geqq 65.1$$

Thus there is a 95% probability that the true MTBF ($\theta$) is included within the above upper and lower limits.

Calculations for Groups AC-10, RT-10, AC-30, RT-30, AC-40, and RT-40 are listed in Table 21. Tables 10 and 15 in Appendix A contain the data used in these calculations.

Table 21  Group MTBF Interval Estimate for a 95% Confidence Level

| Group | AC-10 | RT-10 | AC-30 | RT-30 | AC-40 | RT-40 |
|---|---|---|---|---|---|---|
| STO-04 | Z = 1.97 for a two sided 95% confidence interval | | | | | |
| A | 46. | 23. | 52. | 37. | 7. | 9. |
| B | 48.2 | 132.9 | 65.8 | 90.9 | 414.4 | 376.1 |
| C | Start Calculation | | | | | |
| D | 65.8 | 209.7 | 88.1 | 130.5 | 1034.4 | 824.2 |
| E | 36.7 | 91.8 | 51.1 | 68.2 | 222.1 | 214.7 |

The greater the number of failures observed over a known period of time, the less the uncertainty experienced as shown by the above findings.

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